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The Porosity And Permeability Distribution Of The Shoal Grainstone And Thrombolitic Facies Of The Smackover Formation In Little Cedar Creek And Brooklyn Fields In Southwestern Alabama

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THE POROSITY AND PERMEABILITY DISTRIBUTION OF THE SHOAL GRAINSTONE AND THROMBOLITIC FACIES OF THE SMACKOVER FORMATION IN LITTLE CEDAR CREEK AND BROOKLYN FIELDS IN SOUTHWESTERN ALABAMA

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By

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ABSTRACT

The Smackover Formation is the most prolific hydrocarbon producer in Alabama, with the Little Cedar Creek and Brooklyn Fields being the two largest producers in Alabama. Unlike other Smackover fields Little Cedar Creek Field and Brooklyn Field production is the result of two reservoirs, known as the shoal grainstone and thrombolite (microbial) boundstone. Even with the success of the Smackover Formation, geographic trends of the porosity and permeability are problematic because production is affected. The distribution of the facies also plays a role in the porosity and permeability. The objective of this study is to delineate porosity and permeability trends of the shoal grainstone and thrombolite facies to the lithofacies that appear in Smackover Formation in Little Cedar Creek and Brooklyn Fields.

Seven distinct lithofacies appear throughout the Little Cedar Creek and Brooklyn Fields categorized from top to bottom; (S-1) peritidal lime mudstone-wackestone; (S-2) tidal channel conglomeratic floatstone-rudstone; (S-3) peloid-ooid shoal grainstone-packstone (upper reservoir); (S-4) subtidal lime wackestone-mudstone; (S-5) microbially-influenced packstone-wackestone; (S-6) subtidal clotted peloidal thrombolite boundstone (lower reservoir); (S-7) transgressive lime mudstone-dolostone. The oolitic grainstone (S-3) and thrombolite reservoir (S-6) reservoir are affected by the tidal channel conglomerate facies and the lime mudstone-dolostone facies that emerge within the Smackover.

The data indicates that values for porosity and permeability can be established in Little Cedar Creek and Brooklyn Fields but cannot be the only tools employed to determine future

production within these two fields or other Smackover fields that demonstrate the same quality. The oolitic grainstone is affected by the tidal channel facies, which affects the porosity and permeability and in turn oil and gas production because when the tidal channel appears the oolitic grainstone facies disappears. When the microbially-influenced packstone-wackestone facies is well developed and the lime mudstone-dolostone facies is thick, the thrombolite boundstone facies tends to disappear causing porosity and permeability to be affected.

DEDICATION

This thesis is dedicated to my family, friends, and my girlfriend. Thank you all for your love and support and for continuing to encourage me.

LIST OF ABBREVIATIONS

BBL	Barrels of oils
BCF	Billion cubic feet of gas
BF	Brooklyn Field
LCCF	Little Cedar Creek Field
MISB	Mississippi Interior Salt Basin
GOM	Gulf of Mexico
SOGBA	State Oil and Gas Board of Alabama

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CHAPTER 1

INTRODUCTION

The Upper Jurassic (Oxfordian) Smackover Formation is the most prolific hydrocarbon producer in Alabama and the U.S. Gulf Coast region (Benson et al., 1996; Benson, 1988; Koralegedara and Parcell, 2008). Smackover production has resulted from both structural and stratigraphic traps. Since the discovery of the Upper Jurassic Smackover Formation in Toxey Field in 1967, over 725 wells have been drilled in southwestern Alabama (State Oil and Gas Board of Alabama, 2016). The method for targeting Smackover Formation production in Alabama was to locate microbial buildups overlying paleotopographic highs of Paleozoic basement rocks from seismic profiles (Benson and Mancini, 2000). Discoveries in the Smackover Formation in Vocation Field (Monroe County) and Appleton Field (Escambia County) continued to make this method a common exploration strategy in Alabama because of the recognition of microbial buildups as major hydrocarbon reservoirs (Baria et al., 1982; Parcell, 2000; Llinas, 2004; Mancini et al., 2008). However, this exploration strategy was altered after the discovery of Little Cedar Creek Field (LCCF) in 1994 and Brooklyn Field (BF) in 2007.

Little Cedar Creek and Brooklyn Fields are located in Conecuh and Escambia County, Alabama near the updip limit of the Smackover Formation (Fig. 1). By 2005, there were 23 producing wells in LCCF and in 2012, 26 producing wells were established in BF (SOGBA

2012; Mancini et al., 2006). Exploration in these two fields is different because microbial buildups were not found to overlie paleotopographic highs of Paleozoic basement rocks, but instead overlie conglomeratic sandstone facies of the Norphlet Formation. Geologists recognized that with the development of LCCF, microbial buildups not only developed in bathymetric settings on Paleozoic basement paleohighs, but also developed within updip, nearshore, and shallow to subtidal environments with no apparent underlying structural closure (Mancini et al., 2006; Koralegedara and Parcell, 2008). Oxfordian reefs (thrombolites) developed on top of these Paleozoic basement highs and were overlain by an oolitic grainstone. However, in both fields the thrombolitic boundstone and oolitic grainstone are divided by a dense lime mudstone and wackestone.

The Smackover play in LCCF and BF is different than other Smackover fields in Alabama. First, both fields exhibit no structural closure. Heydari and Baria, (2005) found that further research needed to be done but they believed that the trapping mechanism for LCCF could be a combination of a structural and stratigraphic trap. Further research has shown that each fields trapping mechanism is a pure stratigraphic trap. Second, production is the result of a dual-reservoir system, with the oolitic grainstone facies being the upper reservoir and the thrombolite boundstone being the lower reservoir. These two reservoirs are not in communication with another (Mancini et al., 2008). Thirdly, Smackover facies in southwestern Alabama are heavily dolomitized, causing the original depositional fabric and texture to be altered. This makes its problematic for operators to procure core samples. However, in Little Cedar Creek Field and Brooklyn Field these facies are partially dolomitized allowing for the facies to keep its original depositional fabric and texture. Fourth, the reservoirs are in close proximity to the updip limit of the Smackover Formation (Heydari and Baria, 2005; Mancini et al., 2006; Mancini et al., 2008). Lastly, the Buckner anhydrite member of the Haynesville Formation is typically the top seal of the Smackover grainstone facies. In Little Cedar Creek Field and Brooklyn Field the Buckner anhydrite contact is not present because the Buckner anhydrite does not directly overlie the reservoir but instead is discontinuous and resides over the lime mudstones of the Smackover (Heydari and Baria, 2005; Mancini et al., 2008), which acts as the reservoir seal.

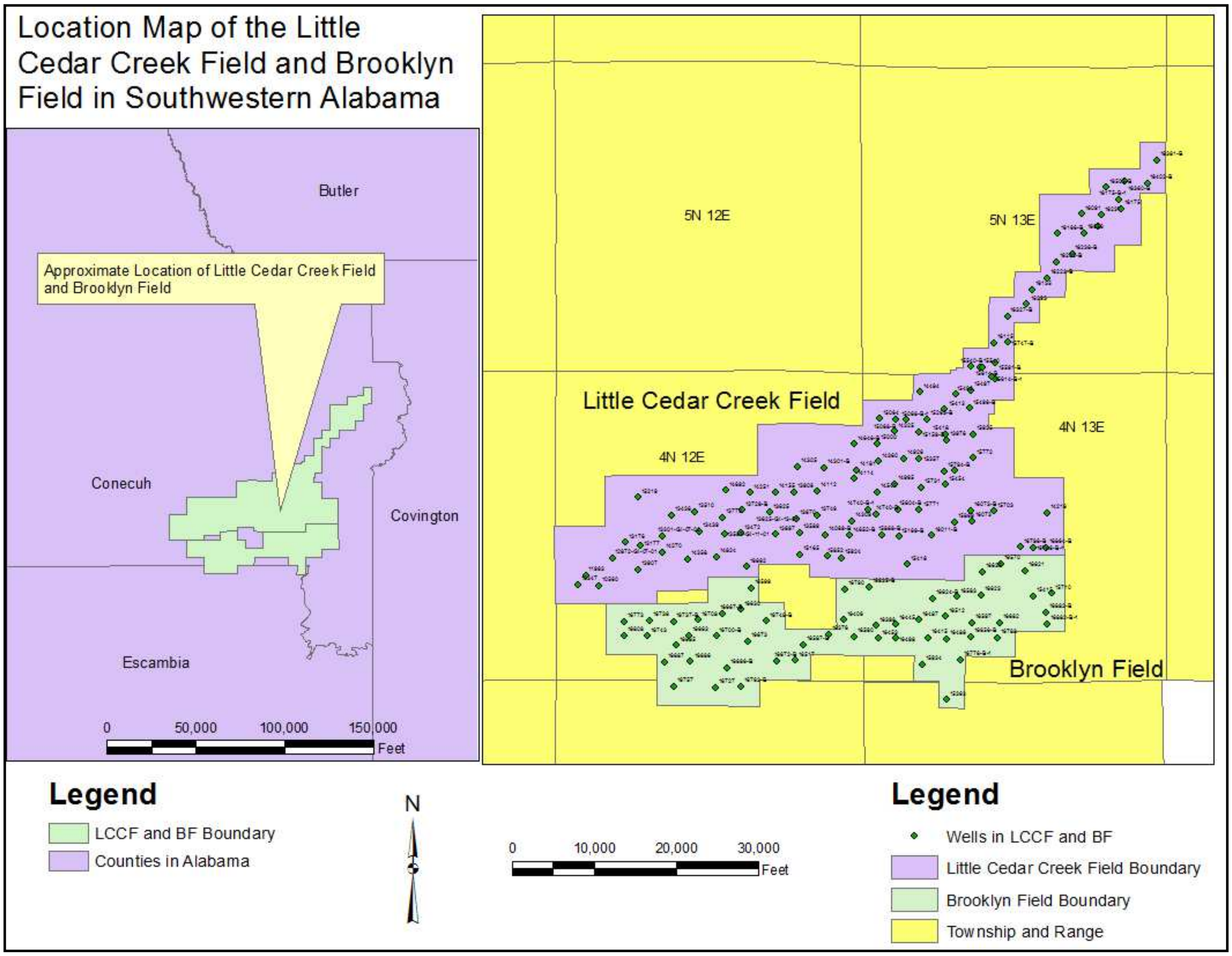


Figure 1. Location Map of Little Cedar Creek Field and Brooklyn Field in Southwestern Alabama

Objective

Even with the advancement of technology, locating Smackover fields in southwestern Alabama is still a rigorous process because the Smackover occurs at depths of 10,000 to 19,000 feet. This results in extremely high drilling costs. Because of the complex nature of the Smackover reservoirs and their small size, the success ratio is about 10% (which has potentially increased because of the advancement of technology) (Benson 1985). Predicting porosity and permeability trends have been one of the major problems encountered during Smackover petroleum exploration. Even after initial discovery production can be uneconomic because of the inability to predict geographic trends in porosity and permeability (Benson 1985; Baria personal communication). Little Cedar Creek Field and Brooklyn Field experience these same trends, and operators in both fields still run into the problems of drilling dry or uneconomic wells (Baria personal communication) (Fig. 2).

Another issue that affects porosity in the reservoirs is the distribution of lithofacies in the Smackover in LCCF and BF. Ridgway (2010) and Day (2014) state that the lower reservoir (thrombolitic boundstone) is more developed when the facies underlying it is thin and the facies overlying it is under developed. Ridgway (2010) and Day (2014) also state that the upper reservoir (oolitic grainstone) disappears when a tidal channel floatstone is present. The changes in these facies affect the porosity and permeability, which is a direct correlation to having productive or non-productive reservoirs.

This study concentrates on the porosity and permeability trends of the Little Cedar Creek Field and Brooklyn Field. An objective of this thesis is the construction of porosity and permeability maps of the shoal grainstone and thrombolitic facies in Little Cedar Creek and

Brooklyn Fields. This should allow for interpretation of geographic trends that could improve development for future production of these two fields and potentially other fields in the Gulf Coast region that have the same characteristics. These maps will be created by analyzing well logs and core analysis to correlate the lithofacies of the LCCF and BF to productive and non-productive wells.

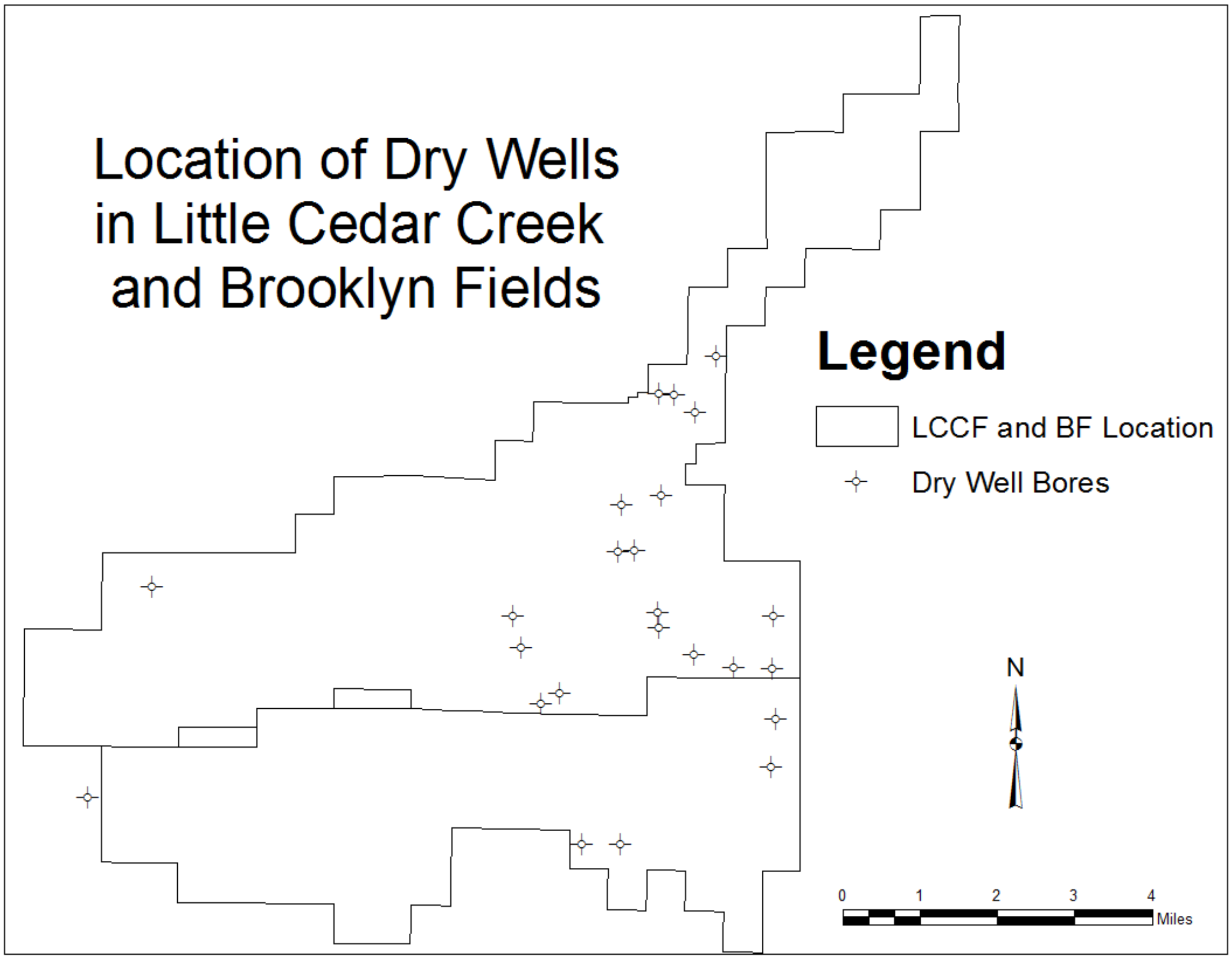


Figure 2. Location of non-producing wells in occurrence with oil production in Little Cedar Creek Field and Brooklyn Field

Location and Field History

The Little Cedar Creek Field (LCCF) was discovered in 1994 when Hunt Oil Company drilled discovery well Cedar Creek Land & Timber Company 30-1 #1 (Geological Survey of Alabama Oil and Gas Board, 2012). The total depth of the well was 12,100 feet and production was from the upper oolitic grainstone in the Smackover Formation. Initial production of the well was 108 barrels per day. In 2000, Midroc Operating Company purchased the leasing rights from Hunt and has completed more than 70 wells in the Smackover reservoir (Geological Survey of Alabama Oil and Gas Board, 2012). On January 1st, 2005 the western portion of Little Cedar Creek Field was unitized in order that multiple field operators could distribute production based on predetermined allocation of the nearly 6,000-acre area; which, allowed for the summing of production of all wells (Breeden, 2013). Sklar Exploration Company LLC drilled its first well in Little Cedar Creek Field in 2006 and since then has completed more than 20 wells in LCCF. Lastly, Midroc Operating Company contracted Pruet Production Company to operate its current wells and to continue field development and develop new ways of drilling (Geological Survey of Alabama Oil and Gas Board, 2012).

Brooklyn Field was discovered by Sklar Exploration Company, L.L.C., in August 2007, by wildcat well Logan 5-7 No.1 Well, Permit No. 15363, which is located three miles south of Little Cedar Creek Field in Escambia County. In January 2009, another wildcat was drilled by Sklar, in Conecuh County, about a mile northwest of the first wildcat well. LCCF and BF are located south of the Conecuh Ridge and north of the Pensacola Ridge in the Conecuh Embayment (Fig. 3). These fields are in the southern portion of Conecuh County and northern portion of Escambia County, Alabama. The BF lies directly south of LCCF and the difference in reservoir pressure separates the two fields. The depositional setting of LCCF and BF is defined as an updip microbial nearshore environment (Mancini et al., 2006).

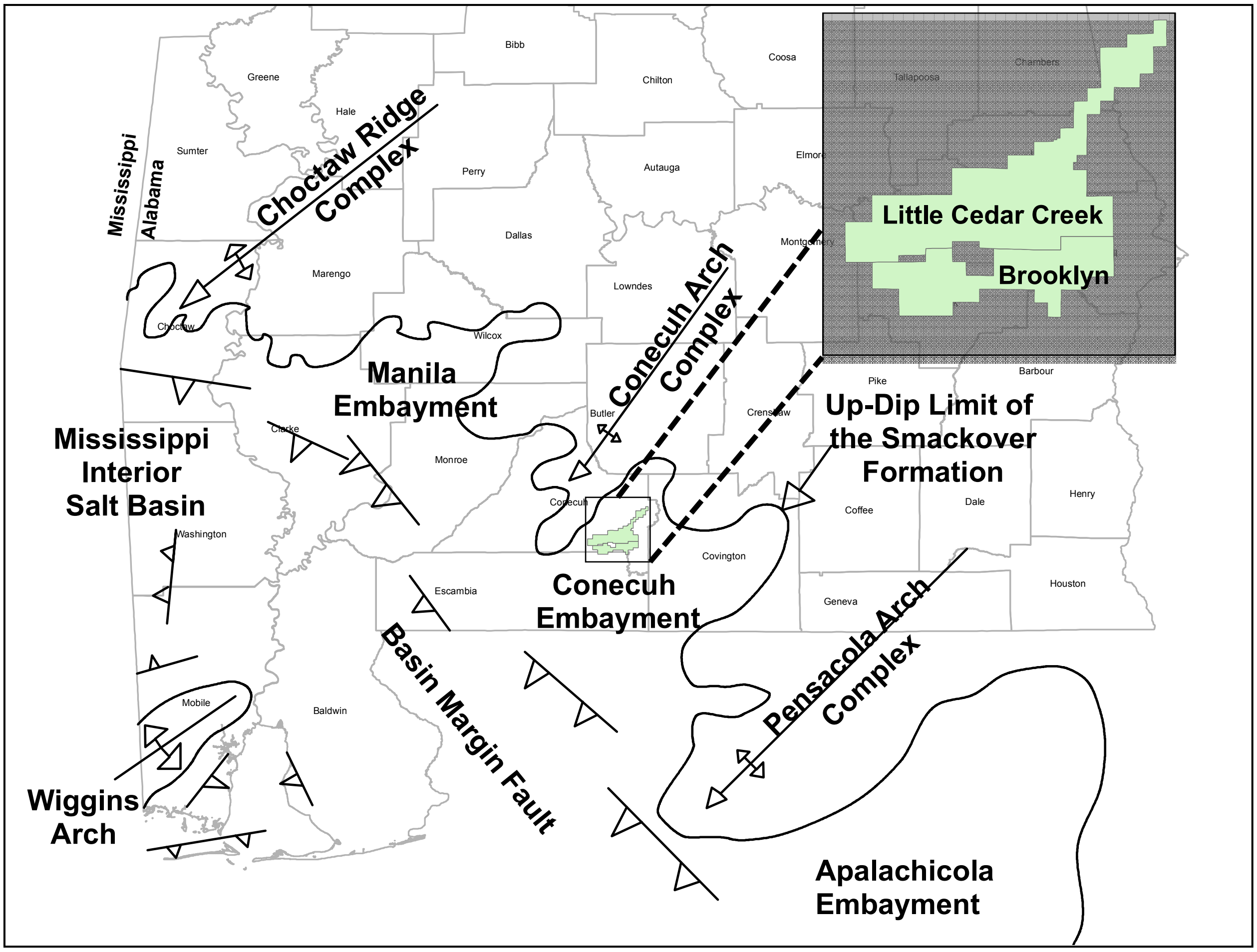


Figure 3. Up-dip limit of the Smackover Formation and major arches and basin located near Little Cedar Creek and Brooklyn Fields. The features in the map are located in southwestern Alabama (Modified from Heydari and Baria, 2005)

CHAPTER 2

GEOLOGIC SETTING

Regional Structure

Breakup of the supercontinent Pangea influenced the deposition in southwest Alabama and the formation of the Gulf of Mexico Basin (Mancini et al., 1991: Salvador, 1991). A series of half-graben basins were created by extensional tectonics associated with sea floor spreading in the Gulf of Mexico (Sandwell et al., 2014). The Conecuh Ridge was one of these ridges (Mancini et al., 2001). The time period of this rifting and opening of the GOM occurred between the Middle Triassic to Late Jurassic. Jurassic deposition and basin setting were influenced by basement subsidence, erosional, and tectonic paleo-highs (Mancini et al., 1991; Wilson, 1975).

Smackover Formation deposition occurred on a ramp-life surface across the northern rim of the Gulf of Mexico (Ridgway, 2010). The shallow shelf model and the ramp model are depositional frameworks; that can help to understand carbonate deposition (Ahr, 1973; Mancini and Benson, 1980). The carbonate ramp model is a sloping topographic surface on which carbonate facies are deposited while subject to open ocean conditions from the surf zone to depth of hundreds of feet (Ahr, 1973). The carbonate ramp is an inclined platform that extends basinward without a break in slope (Mancini and Benson, 1980). The carbonate ramp model facies pattern is opposite the shelf model because the facies displays in a lateral relationship. This relationship is essential for the exploration of carbonate reservoirs because of the distribution of the grainy and muddy facies and occurrence of these facies. Since the shelf-margin barrier does not influence carbonate lithofacies, carbonates are distributed in bands paralleling the coastline and reflect the greater wave and current activity near the shore (Mancini and Benson, 1980). This allows for the development of patch reefs on local topographic paleohighs.

Jurassic sedimentation in southwestern Alabama was influenced by major positive and negative basement features (paleotopographic highs). This was the result of continental collision and extension in the Late Paleozoic and continental rifting in the Late Triassic-Early Jurassic (Wood and Walper, 1974; Martin, 1978; Salvador, 1987). Differential subsidence and paleotopography controlled the plate tectonics framework and influenced the accumulation, and deposition of Jurassic sediments (Tew et. al., 1991). These Jurassic structural developments are associated with halokinesis of the Louann Salt.

The major positive basement features (paleohighs) that have influenced deposition in southwestern Alabama are the Choctaw ridge complex, Conecuh ridge complex, Wiggins arch complex, which include the Wiggins arch and Baldwin high, and the Pensacola-Decatur ridge complex (also known as the Pensacola-Arch Complex)(Fig. 4) (Mancini and Benson, 1980; Mink and Mancini, 1995; Tew et al., 1991).

Basement rocks associated with the Choctaw ridge, Conecuh Ridge, and Pensacola-Decatur ridge complexes formed in the late Paleozoic during the convergence of the North America and African-South American continental plates, co-occurring with the formation of the

Appalachian fold and thrust belt (Mink and Mancini, 1995; Mancini et al., 2003). Large horsts and grabens formed during the Triassic and early Jurassic, due to the regional basement rift system modifying the existing structural grain through a pattern of extensional and wrench basement faults (Martin, 1978; Miller, 1982; Klitgord and Popenoe, 1984; Mink et al., 1990). These three ridge complexes are large horsts that were broad topographically high features during the Jurassic (Mink and Mancini, 1995). The Wiggins arch which extends eastward into Mississippi could potentially represent a continental block that foundered during rifting or possibly a southwestward extension of the Appalachian structural front (Mancini et al., 1984). The Wiggins arch complex is recognized as a remnant of the rifted continental margin of the North American plate features left after the rifting of the Gulf of Mexico in the Jurassic.

The major negative structural features in southwest Alabama not only separate the paleohighs discussed, but they are also associated with Mesozoic depocenters. These structures are the Mississippi Interior Salt Basin, Manila Embayment, and the Conecuh Embayment (Fig.5). Miller (1982) states that these structural features formed as rift grabens and are associated with the opening of the GOM and became areas of sediment accumulation. The Conecuh and Manila Embayments are updip embayments associated with the Mississippi Interior Salt Basin (MISB); MISB is characterized by salt pillows and salt diapirs (Kopaska-Merkel and Mann, 1992; Mink and Mancini 1995). These salt pillows are usually confined to updip areas and the diapirs are found primarily in the central portion of the basin where both salt and overburden are thicker (Kopaska-Merkel and Mann, 1992). The Manila Embayment along with the Conecuh Embayment strata derives from the Jurassic and Lower Cretaceous and unconformably overlies and pinches out against Paleozoic sedimentary rocks and Precambrian and Paleozoic metamorphic and igneous rocks.

In this embayment area, Smackover carbonates were deposited in an inner ramp carbonate ramp setting, under tranquil conditions in bays and lagoons subjected to periodic influxes of freshwater, terrestrial plant material, and terrigenous clay and silt (Al Haddad and Mancini, 2013). The embayment is characterized as a bi-lobate embayment created by the marine transgression onto the southern extension of the Paleozoic Appalachian fold belt; the axis parallels the strike of the buried Appalachian structural salient and trends from a northeast to southwest direction (Prather 1992; Baria et al., 2008). The embayment is roughly 50 miles wide at its mouth and extends inland close to 30 miles; the thickness of the Smackover Formation in the embayment varies depending on the location near the updip and the lateral pinchouts is 0ft and near the seaward portion of the central axis the range is 320ft. The present structural configuration of the Smackover surface within the embayment is a simple monoclonal dip toward the southwest at a rate of roughly 150ft/mi (Baria et al., 2008).

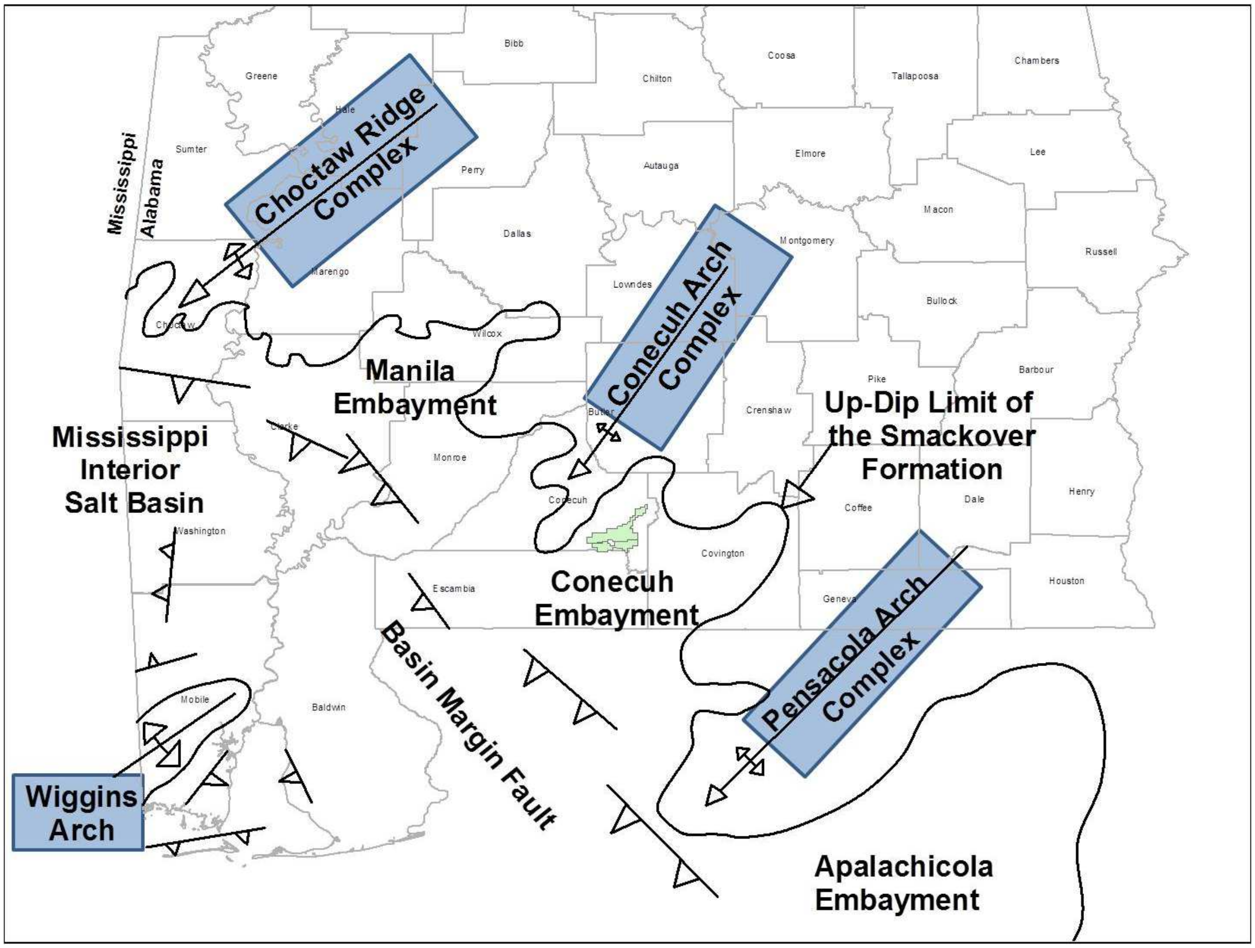


Figure 4. Major positive basement features (highlighted in blue) that influenced deposition in southwestern Alabama

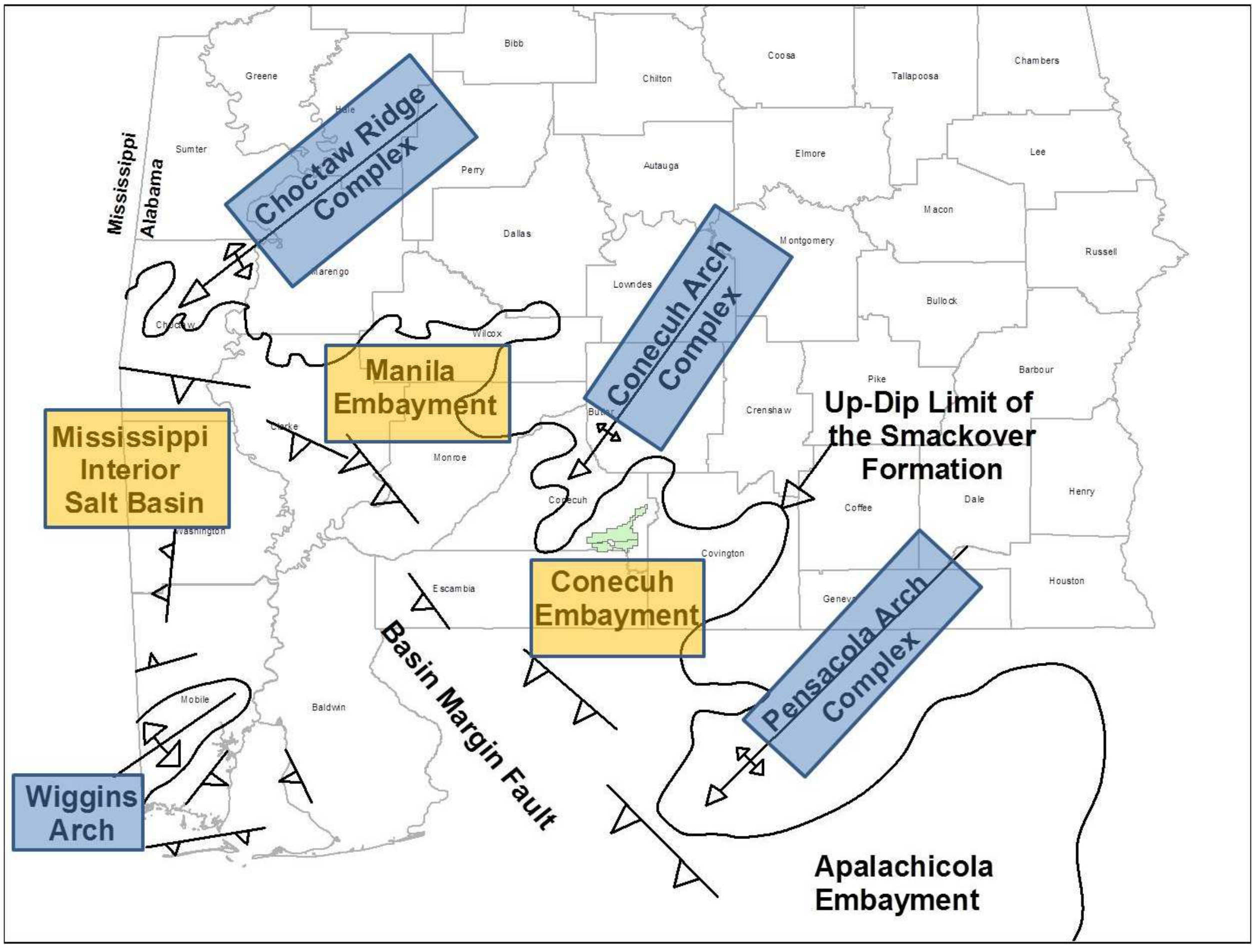


Figure 5. Major negative structural features (highlighted in yellow) that separate the positive structural features (blue) and are associated with Mesozoic depocenters

CHAPTER 3

REGIONAL STRATIGRAPHY

Haynesville Formation

Salvador (1987) established that the Haynesville Formation was of Kimmeridgian in age and conformably overlies the Smackover Formation. Mancini et al., (1990) and Salvador (1987) broke up the Haynesville Formation into three units, with the Buckner Anhydrite Member being the lower unit that conformably overlies the Smackover Formation; the Frisco City Sand being the middle unit; and the upper Haynesville includes interbedded carbonate mudstones, dolomitic limestones, sandstones, shales, and anhydrites (Mancini et al., 1991; Tolson et al., 1983).

The Buckner Anhydrite Member consists of massive anhydrite with intercalated dolomite beds; in the absence of the Buckner Member, the lower part of the Haynesville consists of massive anhydrite shale, and sandstone and thin anhydrite beds and salt stringers (Mancini et al., 1990; Tolson, 1983). Getz (2012) explains that most oil and gas pools in the Smackover are overlain by Buckner Formation anhydrites, which forms the field caprocks and could have potentially supplied magnesium rich brines that helped to dolomitize the underlying Smackover (Oxfordian) limestone reservoirs over large areas. The Frisco City Sand is the middle unit, which unconformably overlies and consists of plagioclase arkoses and subarkose sandstone (Mann et al., 1989). The Frisco City Sand produces oil and has been interpreted to represent braided stream deposits associated with alluvial fans, and shallow marine, braid delta-front (Stephenson et al., 1993; Mann et al., 1989).

Smackover Formation

The Smackover Formation is a Late Jurassic carbonate unit that subcrops around the northern rim of the GOM basin (Benson, 1988). The Smackover Formation is underlain by the fluvial, eolian, and marine clastics of the Norphlet Formation (Fig. 6); with the uppermost part of the Norphlet formation being the marine clastics (Benson, 1988; Kopaska-Merkel and Mann, 1991). Thicker Smackover deposits occur in the Manila and Conecuh Embayments, than occur on the Choctaw, Conecuh, and Pensacola-Decatur Ridge complexes (Mink and Mancini, 1995). The Smackover Formation was broken into three distinct members based on the change of lithology: lower, middle, upper members (Mancini and Benson, 1980; Baria et al., 1982; Benson, 1988).

The lower member consists of a thin basal intertidal to subtidal sequence of algal laminated mudstone and peloidal oncolitic wackestone and packstone; a thick middle unit of dominantly subtidal sequence of laminated mudstone interbedded with peloidal and skeletal wackestone and packstone; and a thick upper sequence of subtidal to supratidal oolitic, oncolitic, and peloidal grainstone and packstone interbedded with laminated mudstone (Mancini and Benson, 1980; Benson, 1985; Benson, 1988; Claypool and Mancini, 1989).

In southwestern Alabama the Smackover grainstone reservoir is primarily overlain by the Buckner Anhydrite, a regressive unit whose basal portion is dominated by subaqueous evaporates in depositional basins, and by peritidal and supratidal evaporitic and siliciclastic strata on the flanks and crests of paleohighs (Dickinson, 1962; Harris and Dodman, 1982; Moore, 1984; Moore, 1986; Lowenstein, 1987; Mann, 1988, 1990). Heydari and Baria (2005) examined the LCCF and BF and realized that this contact was not present in these two fields. The Buckner

Anhydrite does not directly overlie the reservoir but instead is discontinuous and resides over the lime mudstones of the Smackover (Heydari and Baria, 2005; Mancini et al., 2008).

Norphlet Formation

The Norphlet Formation underlies the Smackover Formation and overlies the Louann Salt when it is present with a conformable contact (Mancini et al., 1992; Tew et al., 1991). When the Louann Salt is not present the Norphlet Formation disconformably overlies other basement rocks or the Eagle Mills Formation (Tolson et al., 1983; Mink et al., 1985). The contact between the Norphlet and the Smackover in southwestern Alabama can be gradational to abrupt. In some parts of southwestern Alabama the contact can be either conformable or sharp, when conformable the lithology grades downward from silty dolostone or limestone to dolomitic or calcitic sandstone. If the contact happens to be sharp, then there can be two different stratigraphic columns to describe the lithology of the contacts based on the location. The first being a carbonate mudstone overlying quartzose sandstone and in updip areas the Smackover Formation overlies Norphlet conglomeratic sandstone (Mancini et al., 1984). In the study area LCCF and BF disconformably overly the Norphlet Formation, conglomeratic alluvial fan facies consisting of igneous and metamorphic clasts enclosed in a sandstone matrix and the contact is sharp (Ridgway, 2010).

In updip parts of the study area Norphlet deposition began with the deposition of shale in isolated lagoons or bays and then with the erosion of the Appalachian Mountains, the Norphlet sandstone began to accumulate (Mancini et al., 1985). The Norphlet is predominantly a continental siliciclastic deposit; is regionally extensive and found in the subsurface throughout the study area (Tew et al., 1991). The thickness of the Norphlet in southwestern Alabama ranges from 0 to 800 feet and is dominated by quartzose sandstone which thickness ranges up to 600 feet.

Within the Norphlet Formation four distinct lithofacies have been discovered (Wilkerson et al., 1981; Mancini et al., 1985; Marzano et al., 1988). The Norphlet consist of an discontinuous basal black shale, conglomeratic sandstone, red beds, and the upper quartzose sandstone known as the Denkman Sandstone Member Mancini et al., 1985; Tew et al., 1991). The upper part of the Denkman Member is a massive to indistinctly horizontal, discontinuous, wavy, and a laminated sandstone (Mancini et al., 1985). The lower Denkman Member consists of lower high-angle, cross-bedded sandstone, laminated dune sandstones, and horizontally laminated dune and interdune sandstones (Mancini et al., 1984). In the updip parts of Escambia the red beds become the dominant lithology of the Norphlet; in further updip parts of Conecuh and Escambia Counties the Denkman Member and red beds are replaced by the conglomeratic sandstone, which can be seen in LCCF and BF. Lastly, the black shale appears at the base of the Norphlet.

Era	System	Series	Stage	Formation
Mesozoic	Jurassic	Upper Jurassic	Kimmeridgian	Haynesville Formation
			Oxfordian	Smackover Formation
		Middle Jurassic	Callovian	Norphlet Formation

Figure 6. Generalized stratigraphic column of the Smackover Formation of Little Cedar Creek Field and Brooklyn Field.

Petroleum Geology

In southwest Alabama hydrocarbon production in the Smackover Formation is a result of combination traps which involves stratigraphic traps and salt anticlines, faulted salt anticlines, or extensional fault traps associated with salt movement or with the updip limit of the Louann Salt deposition (Mancini and Benson, 1980). The reservoir rocks in southwest Alabama include grainstones; leached and dolomitized wackestones, packstones, and grainstones; and dolomite (Mancini and Benson, 1980). Interest has grown in the updip Smackover play associated with the microbial buildups in a carbonate ramp-type setting because of the discovery of LCCF and BF (Ridgway, 2010). The Smackover reservoir in LCCF and BF is mainly limestone because the facies within these two fields keep their original depositional fabric because they are not heavily dolomitized. This has helped in the characterization of Smackover facies in LCCF and BF because there are over 170 cores in LCCF and BF.

Little Cedar Creek and Brooklyn Fields hydrocarbons have been described as pure stratigraphic traps that developed near the updip limit of the Smackover Formation because there is no sign of structural closure. Since their discovery LCCF has produced 19 million barrels of oil (MMBL) and 24 billion cubic feet of gas (BCF) and BF has produced 12 (MMBL) and 12 (BCF) as of May of 2015 (Fig. 7-8). The reservoir rock textures of LCCF and BF are similar to other Smackover fields that have produced from microbial buildups in southwestern Alabama, which include high-energy grainstone, packstone, and microbial boundstone (Mancini et al., 2004). The oolitic grainstone (upper reservoir) and thrombolite boundstone (lower reservoir) are not in communication with other because they are separated vertically by a lime mudstone unit. For other Smackover fields in southwestern Alabama the grainstone reservoir directly overlies the microbial boundstone reservoir (Mancini et al., 2004). The porosity of the thrombolitic boundstone in LCCF and BF chiefly consists of vuggy pores, and the porosity of the oolitic grainstone reservoir mainly includes grain-moldic pore types (Mancini et al., 2006).

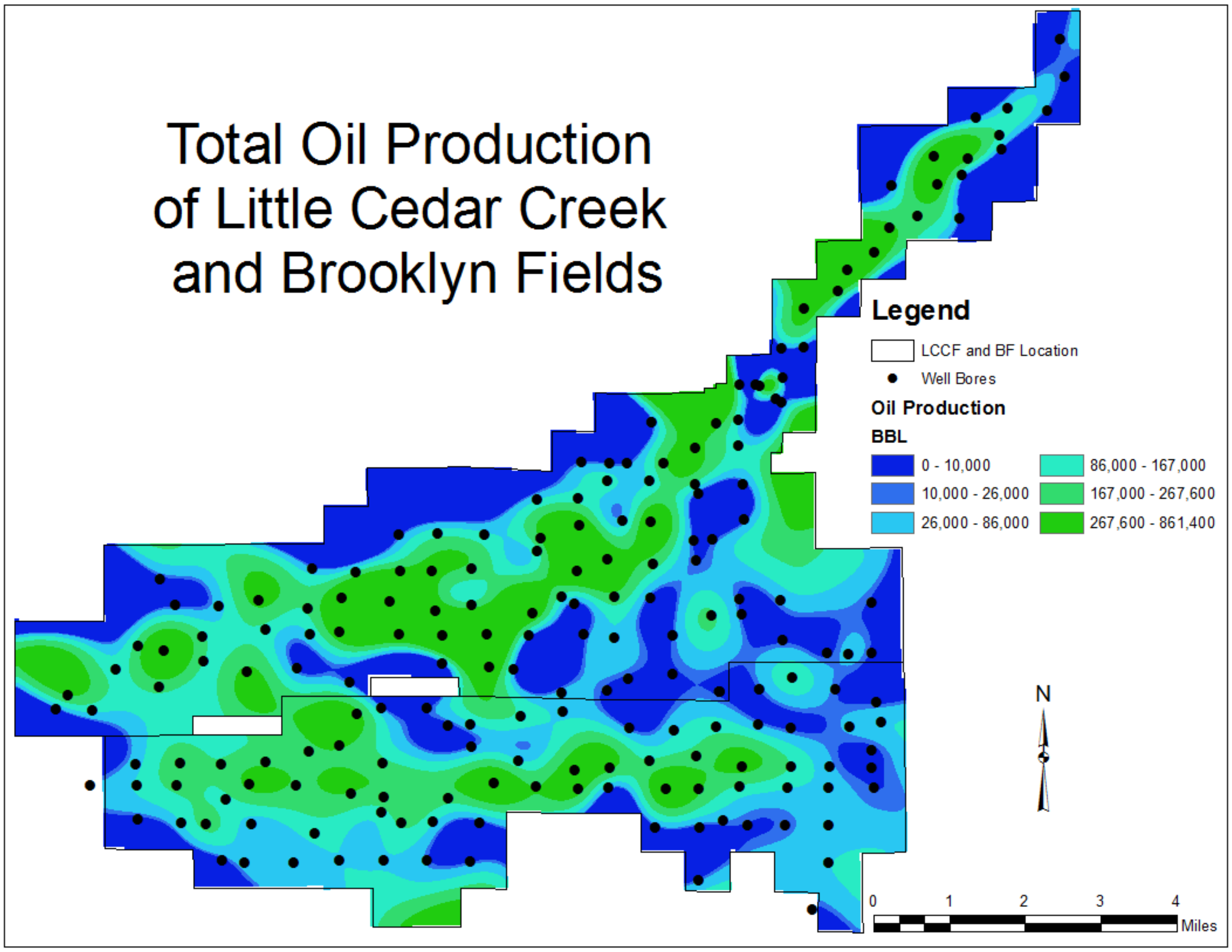


Figure 7. Total Oil Production of Little Cedar Creek and Brooklyn Fields in southwestern Alabama

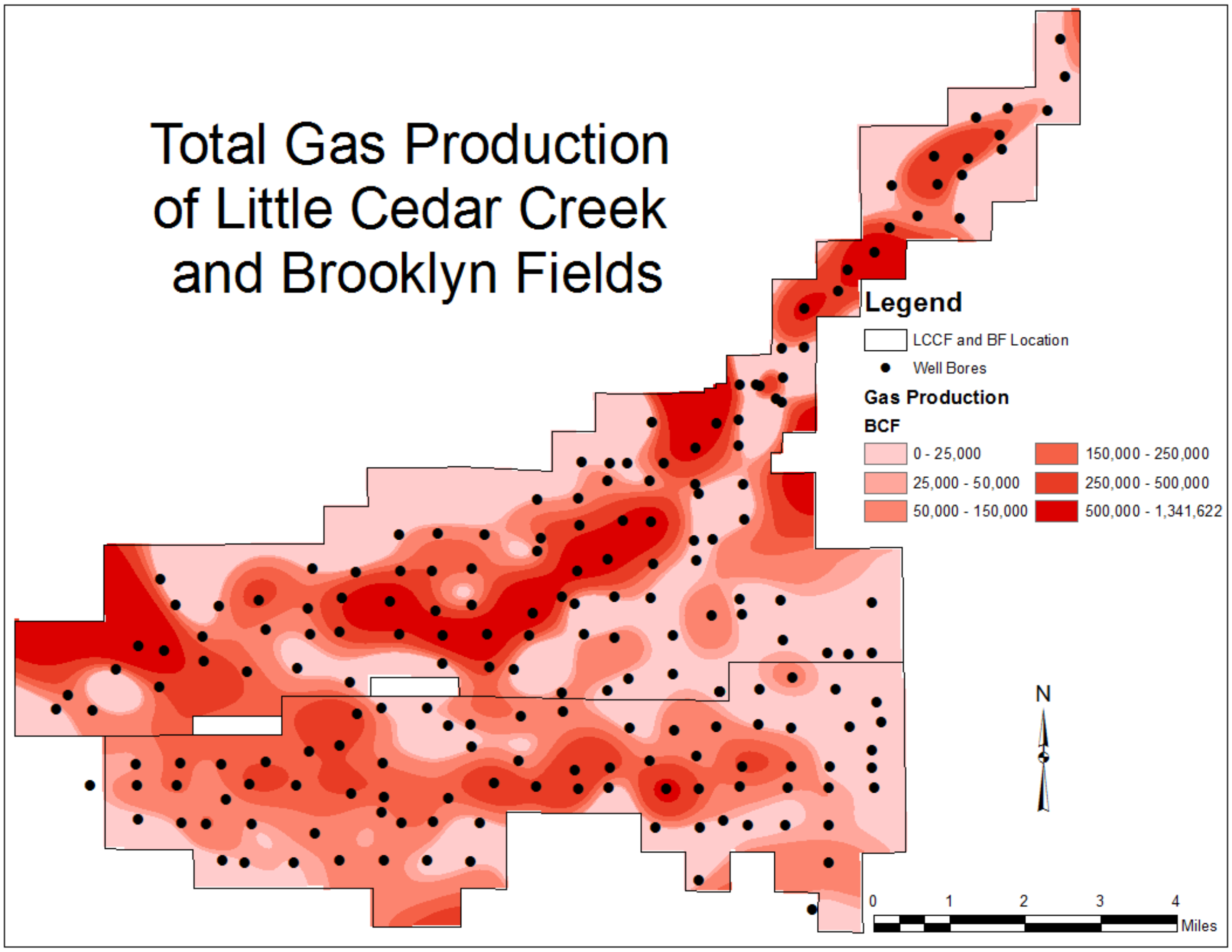


Figure 8. Total Gas Production of Little Cedar Creek and Brooklyn Fields in southwestern Alabama

CHAPTER 4

LOCAL STRATIGRAPHY

This study does not characterize the facies located in LCCF and BF but utilizes the descriptions given by Ridgway (2010), Al Haddad and Mancini (2013), and Day (2014). Ridgway (2010) described the seven different lithofacies within LCCF and Day (2014) described these same lithofacies but in both LCCF and BF, making this the first study done on Brooklyn Field. Within these seven facies there are two productive reservoirs. So each description will come from their analyzes of the facies.

The facies described from the top-bottom of the Smackover Formation are: (S-1) peritidal lime mudstone-wackestone; (S-2) tidal channel conglomeratic floatstone-rudstone; (S-3) peloid-ooid shoal grainstone-packstone (upper reservoir); (S-4) subtidal lime wackestone-mudstone; (S-5) microbially-influenced packstone-wackestone; (S-6) subtidal clotted peloidal thrombolite boundstone (lower reservoir); (S-7) transgressive lime mudstone-dolostone (Fig. 9-10).

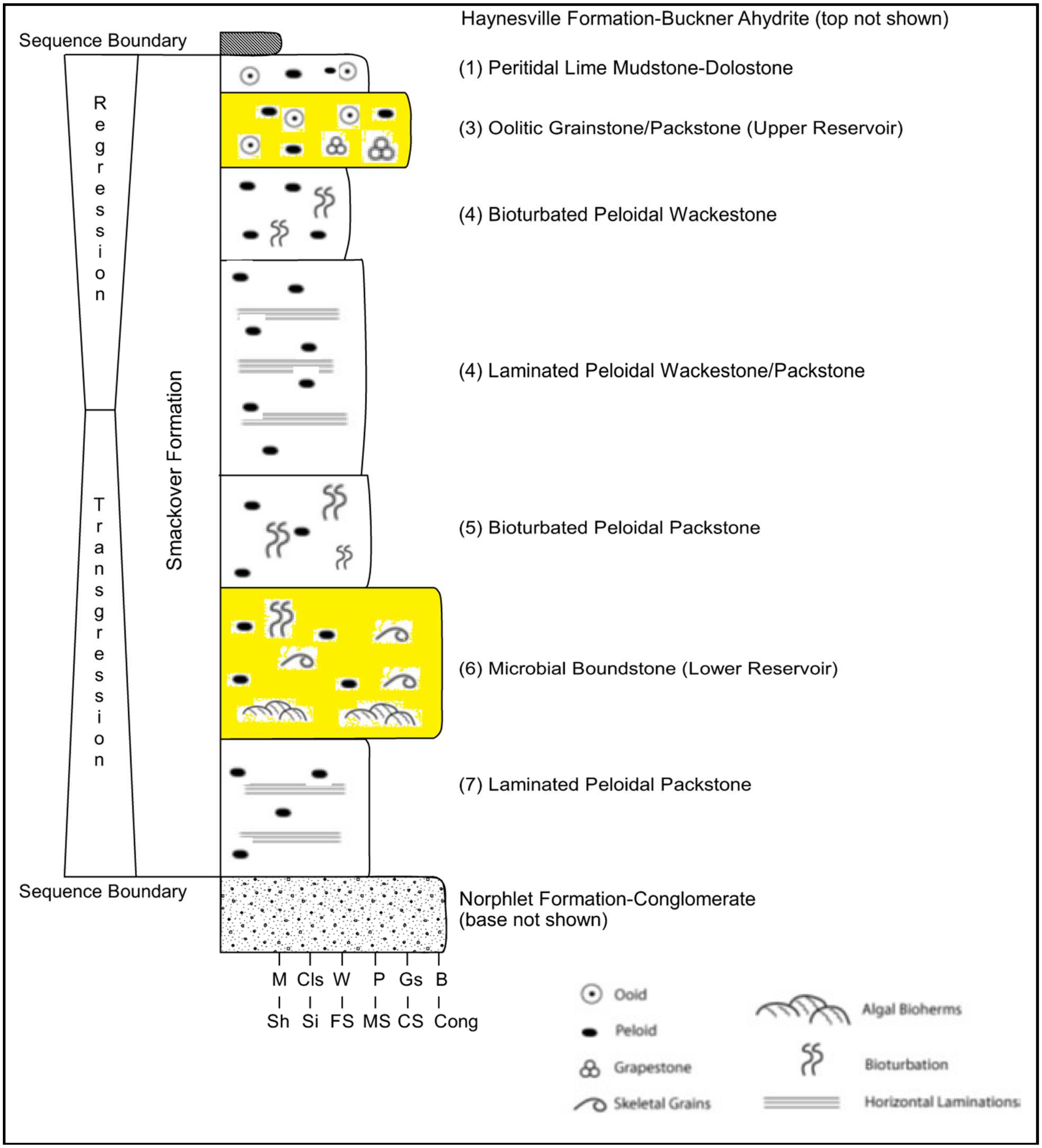


Figure 9. Idealized Stratigraphy of the seven units excluding the (S-2 facies) of the Smackover Formation in Little Cedar Creek and Brooklyn Fields, Conecuh County, Alabama. (M-mudstone, Cls-calcisiltstone, W-wackestone, P- packstone, Gs-grainstone, B-boundstone) and the Wentworth size classification for siliciclastics (Sh-shale, Si-siltstone, FS-fine sandstone, MS-medium sandstone, CS- coarse sandstone, Cong-conglomerate). This study focuses on the yellow highlighted upper and lower reservoir. (Modified from Mancini et al., 2002, Breeden, 2013).

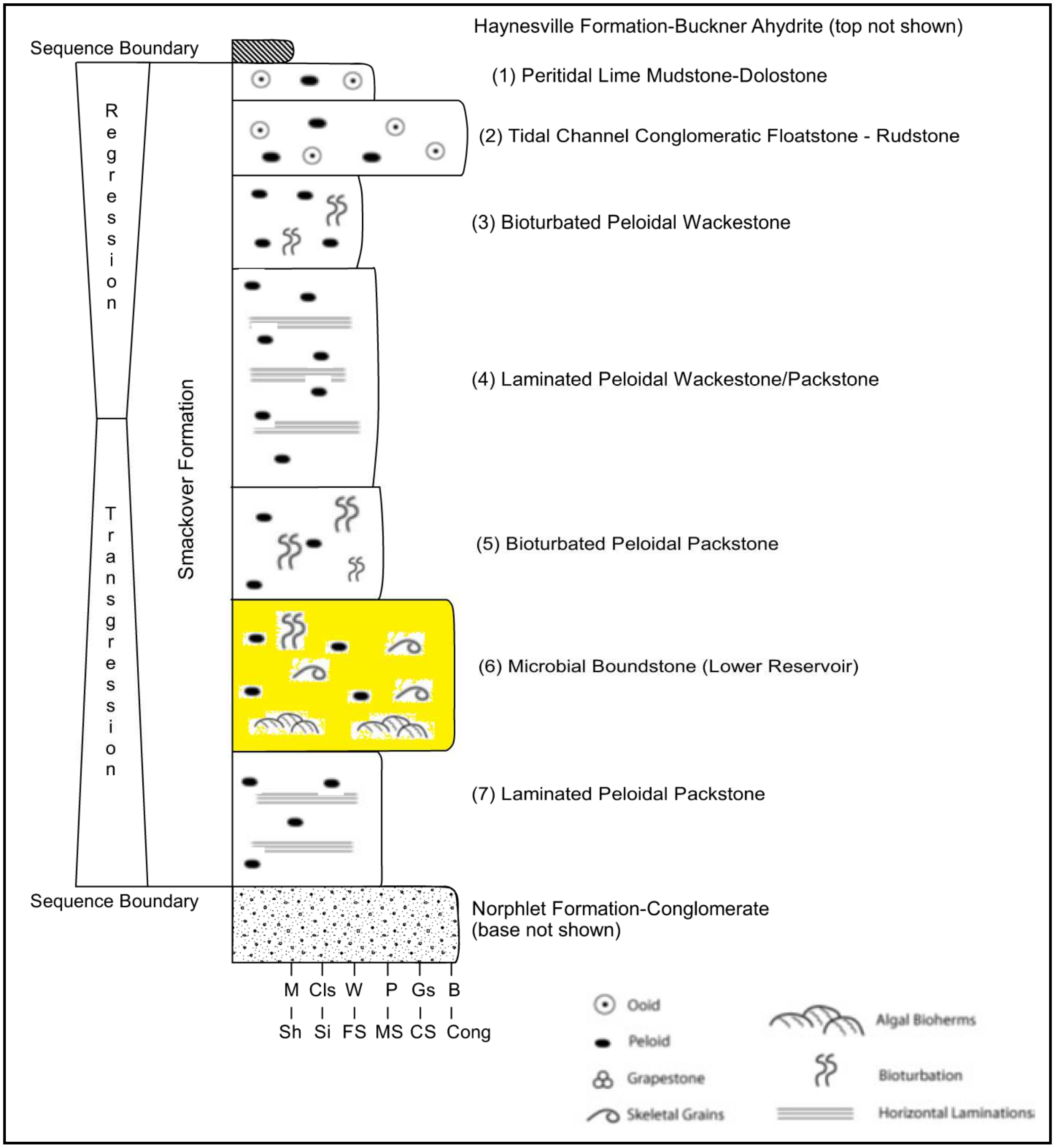


Figure 10. Idealized Stratigraphy of the seven units excluding the (S-3 facies) of the Smackover Formation in Little Cedar Creek Field and Brooklyn Field, Conecuh County, Alabama. (M-mudstone, Cls-calcisiltstone, W-wackestone, P- packstone, Gs-grainstone, B-boundstone) and the Wentworth size classification for siliciclastics (Sh-shale, Si-siltstone, FS-fine sandstone, MS-medium sandstone, CS- coarse sandstone, Cong-conglomerate). This study focuses on the yellow highlighted upper and lower reservoir. (Modified from Mancini et al., 2002; Breeden, 2013)

Lithofacies

S-1 Peritidal Lime Mudstone-Dolostone

The lithology of this facies is a lime mudstone to dolomudstone and is gray to light gray in color. The allochemical constituents it contains are peloids, ooids, benthic foraminifera, and subangular silt. The accessory minerals are dolomite, anhydrite, gypsum, and salt; the sedimentary structures are dolomitic to anhydritic shale laminae with minimal styolites, bioturbation, and burrows. Lastly, this unit is cemented by calcite and anhydrite and has a texture of a mudstone to wackestone.

As evidenced by the presence of evaporitic minerals the unit was deposited in shallow water, near to back shoal, low energy, lagoon environment. The overlying laminated argillaceous, anhydritic sabkha facies of the Haynesville Formation indicates quiet, tranquil conditions. This facies acts as the upper seal, both vertically and laterally instead of the Buckner Anhydrite or the Haynesville argillaceous beds.

S-2 Tidal Channel Conglomeratic Floatstone-Rudstone

The tidal channel floatstone is defined as a limestone with more than ten percent of contained grains larger than two millimeters with a micrite matrix and is light gray in color with multi-pebble assemblage. The allochemical constituents are rounded to subrounded granitic pebbles, peloids, ooids, and silt. The accessory minerals are rounded to sub-rounded monocrystalline and polycrystalline quartz with volcanic pebbles; the sedimentary structures are cross laminated to laminated with wavy bedding. Lastly, is cemented by a sparry calcite and has the texture of a rudstone to floatstone in small intervals.

Deposition took place in a tidal channel environment, because of the presence of pebbles and bedding characteristics, indicating the clasts were reworked and eroded from an updip incised channel. The tidal channel was not perennial and the peloids and ooids associated with the facies indicate a normal high energy shoreline at the time of deposition. Ridgway (2010) and Day (2014) suggest different origins for the tidal channel. Ridgway (2010) states that subrounded-to-rounded, elongate pebbles are similar in composition to angular clasts of the Norphlet Formation, while Day (2014) states this facies are associated with the Buckner facies.

The most significant aspect of this facies is when it is present it replaces the S-3 ooid grainstone facies (upper reservoir), affecting deposition of the S-3 ooid grainstone shoal so extensively, that shoal development ceases when the S-2 tidal channel floatstone-rudstone is present.

S-3 Peloid-Ooid Shoal Grainstone-Packstone (Upper Reservoir)

This facies is defined as a partially dolomitized limestone, light brown to tan to grey in color, and its allochemical constituents are peloids, ooids, *Parafavareina* sp. pellets, skeletal fragments, oncoids, intraclasts, and grapestones. These facies contains cross laminated textures ranging from the dominate grainstone to packstone to mudstone. The acessory minerals are calcite and minor dolomite rhombs and the biogenic structures are oncoids, bioturbations, and burrows. The cements present are dogtooth sparry calcite, and minor bladed calcite. This facies developed as the upper reservoir because its porosity ranges from 0-35% and its porosity type characteristics are intergranular and leached secondary oomoldic to bimoldic porosity types. Effective porosity is diminished due to the lack of interconnectedness of moldic pores.

This facies was deposited in a high-energy, sub-littoral to intertidal shoal environment. The excess of intraclasts and cross lamination shows that the oolitic grainstone developed in high energy near-shore shallow water, sub-tidal to intertidal shoal setting. The plethora of ooids, peloids, skeletal fragments, and pellets indicated that water circulation and wave energy increased over time. The oolitic grainstone attained maximum thickness in the central part of LCCF; this facies is absent in wells located in the northeastern portion of LCCF. But in BF the ooid grainstone facies is the dominant reservoir.

S-4 Subtidal Wackestone-Lime Mudstone

This facies is defined as a lime mudstone, gray to dark gray in color, and contains textures ranging from mudstone to packstone to wackestone. Its allochemical constituents are peloids, pellets, and oncoids; the sedimentary and biogenic structures present are stylolites, microstylolites, minimal algal features, bivalve fragments, and oncoids. The acessory mineral is dolomite; this facies is cemented by calcite and is laminated and wavy. Also serves as the lateral and vertical seal of the underlying S-6 thrombolite boundstone facies.

The facies developed in deeper water sub-tidal marine environment as evidenced by the lack of coarse material and the abundance of mud material. The mud-supported texture indicates low-energy deeper water condition, representing a transition from a transgressive system tract to a regressive system tract.

S-5 Microbially-Influenced Packstone-Wackestone

The facies is defined as a limestone, gray to dark gray in color, and allochemical constituents are peloids, algal filaments, micritized pellets, and oncoids. The sedimentary and biogenic structures of the facies are subangular styolites, styolites, microstylolites, algal and microbial mats, mesoclots, and oncoids. The primary mineral is dolomite and the texture of this unit is packstone-wackestone.

Deposition began in a subtidal marine environment and microbial development is as extensive as in the thrombolite facies but developed in slightly deeper water. Because this facies developed in deeper water conditions, this inhibited microbial development. This facies is likely laterally equivalent in part to the S-6 facies thrombolite boundstone because when this facies is well-developed (core reports) the S-6 (thrombolite boundstone) is not present or has minimal growth; making the S-6 facies in those areas not a good source for hydrocarbons.

S-6 Thrombolite (Microbial) Boundstone (Lower Reservoir)

The microbial thrombolite is a dolomitic limestone, dark to light gray to tan in color; with a boundstone texture. The allochemical constituents of this facies are peloids, benthic foraminifera, micritized pellets, algal filaments, and *Parafavareina* pellets. The sedimentary and biogenic structures are clotted peloid clusters, subangular stylolites, microstylolites, clustered algal filaments, and microbial framework. The thrombolite facies exhibits extensive diagenetically modified fabrics, in the form of interparticle and vuggy porosity.

The thrombolite was deposited in a low-energy shallow water environment as evidenced by the microbial framework produced by cyanobacteria, *Tubiphytes* sp. and algae, indicating conditions which promoted photosynthetic, opportunistic growth among these organisms. The low occurrence of skeletal fragments and bioclasts indicate a low faunal diversity. The thrombolite facies is a major reservoir in the LCCF and has three major buildups. In addition to the buildups in the LCCF, smaller buildups occur in the BF.

S-7 Transgressive Lime Mudstone-Dolostone

This facies is defined as a limestone to dolostone unit, gray to reddish pink in color, with a mudstone to wackestone texture. The allochemical constituents are peloids and dolomite rhombs; the sedimentary and biogenic structures are laminated to mottled fabric and subtle microbial mats and clots and bioturbations. This facies is composed of lime mud, subangular silt and pressure dissolution stylolites and contains thin horizontal laminations near the base that grade into peloid rich microbial mat features with wavy bedding at the top.

The lime mudstone-dolostone was deposited during a rapid marine transgression during the Oxfordian stage. This facies disconformably overlies the Norphlet Formation which indicates a rapid, but calm, marine transgression occurring below the wave base in a mid-ramp environment. When this facies is thick the thrombolite reservoir is minimal or non-existent.

CHAPTER 5

METHODOLOGY

Data

Approximately 208 wells have been drilled in LCCF and BF, and core samples were able to be extracted from nearly every well in the area. This analysis examined 200 core analysis reports, 157 wireline logs, and production data. These reports were collected from both the SOGBA and Jura-Search, Inc. Of the 200 wireline logs, 16 of them were used for correlation of the lithofacies located within the Smackover Formation.

Methods

The initial part of the analysis began with extracting data from the SOGBA and importing it into ArcMap. Then the data were extracted from ArcMap and imported into Microsoft Excel. Excel was used for the core analysis reports for categorization of the porosity and permeability of oolitic grainstone and thrombolite boundstone of LCCF and BF. The core analysis report provides porosity, permeability, water saturation and oil saturation of the bulk/pore volume. For this study, porosity and permeability were the only parameters used for interpretation.

The porosity analysis did not utilize a cut-off percentage but instead a stratigraphic threshold based on when the oolitic or vuggy characteristics appeared within the core analysis report. The porosity values were added from the beginning (top) of the facies to the end (bottom); then divided by the total number of feet to get an average porosity of the facies. This same process was completed for the permeability of both the oolitic grainstone and thrombolite facies. This allowed for porosity, permeability, and isopach thickness maps to be constructed for the oolitic grainstone and thrombolite facies of the LCCF and BF (Fig. 11-16).

The core analysis report provides the porosity, permeability, water saturation and oil saturation of the bulk/pore volume. Since, the core reports use the original measured depth at the time of coring; the gamma ray curve of the core can be correlated to the gamma ray curve of the wireline log for depth correction.

In addition, geophysical wireline logs were also collected to determine the top and bottom of the Smackover Formation. The method used to determine the tops and bottom was the gamma ray, neutron porosity, and density porosity curves. These three methods can be used if the gamma ray curve is hard to interpret by examining the porosity values and the relative position of the density and neutron porosity curves. The contact between the Haynesville-Smackover and Smackover-Norphlet can be determined by utilizing the density-neutron porosity curve combination because the curve overlays when moving through a limestone unit, but separates when it encounters a different lithology, such as anhydrite or sandstone (Ridgway, 2010; Baria personal communication).

Next, 16 well logs were selected for interpretation from the SOGBA (Fig. 17). These 16 well logs were broken down by selecting 4 producing and non-producing wells for each field. In both fields, the well log correlations will show the presence of both reservoirs in the producing wells; the non-producing wells will show how these two reservoirs are not present. This method was chosen because Day (2014) and Ridgway (2010) state that the S-3 facies (oolitic grainstone) ceases when the S-2 facies (tidal channel floatstone-rudstone) appears and the S-6 facies (thrombolite boundstone) is not present when the S-7 facies is thick. EasyCopy was used to create stratigraphic cross-sections of the lithofacies within these wells.

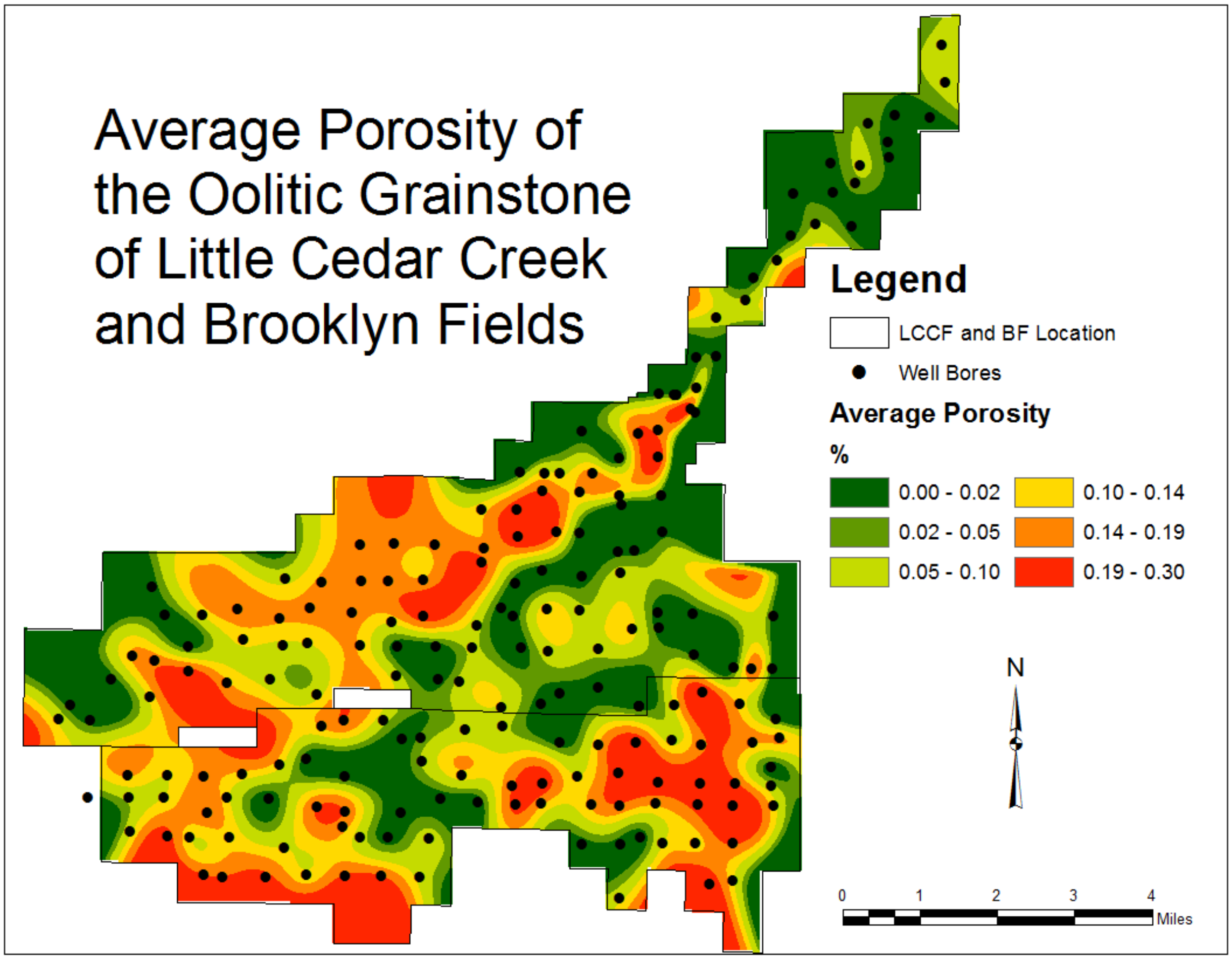


Figure 11. Porosity of the Oolitic Grainstone of Little Cedar Creek Field and Brooklyn Field

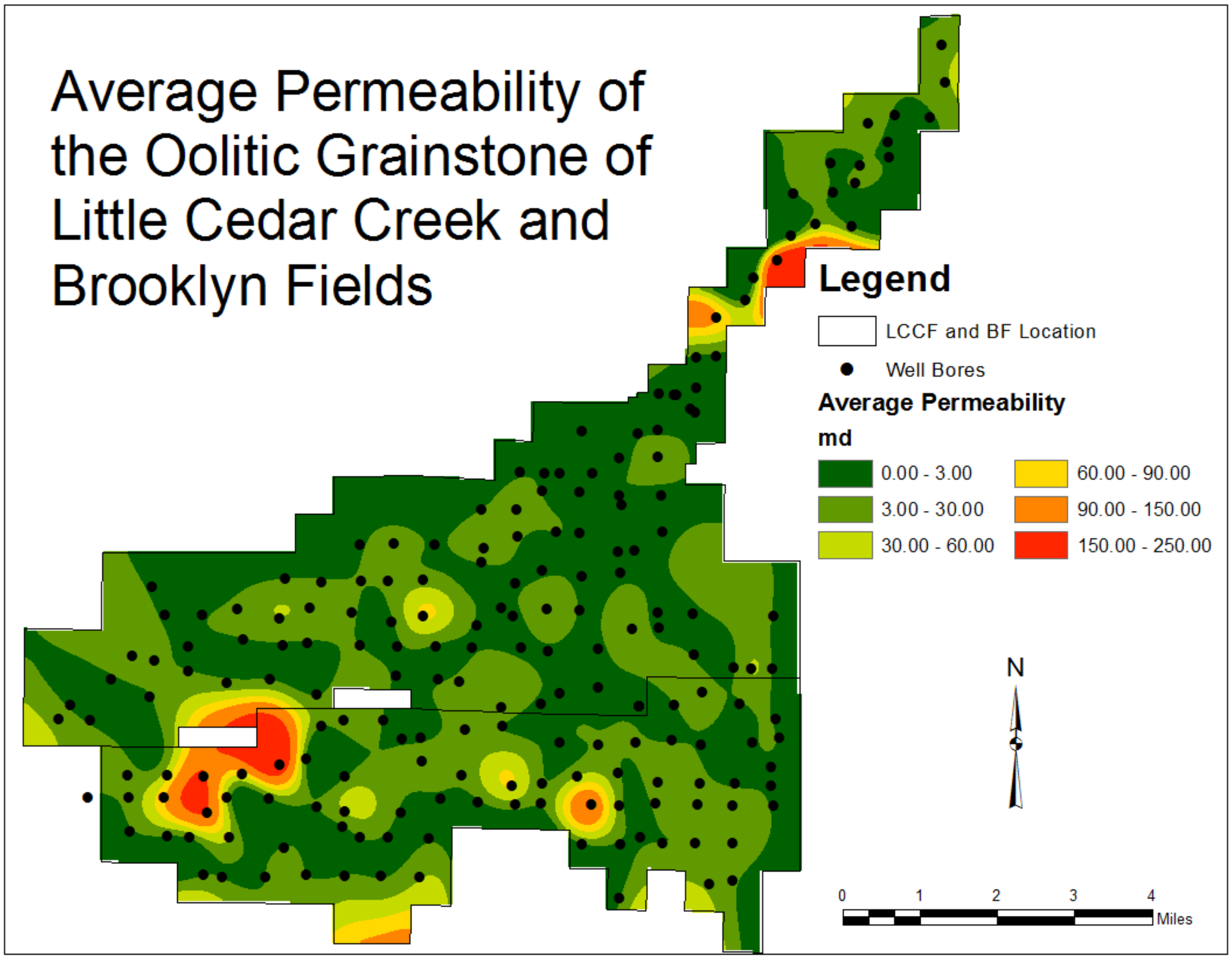


Figure 12. Permeability of the Oolitic Grainstone of Little Cedar Creek Field and Brooklyn Field

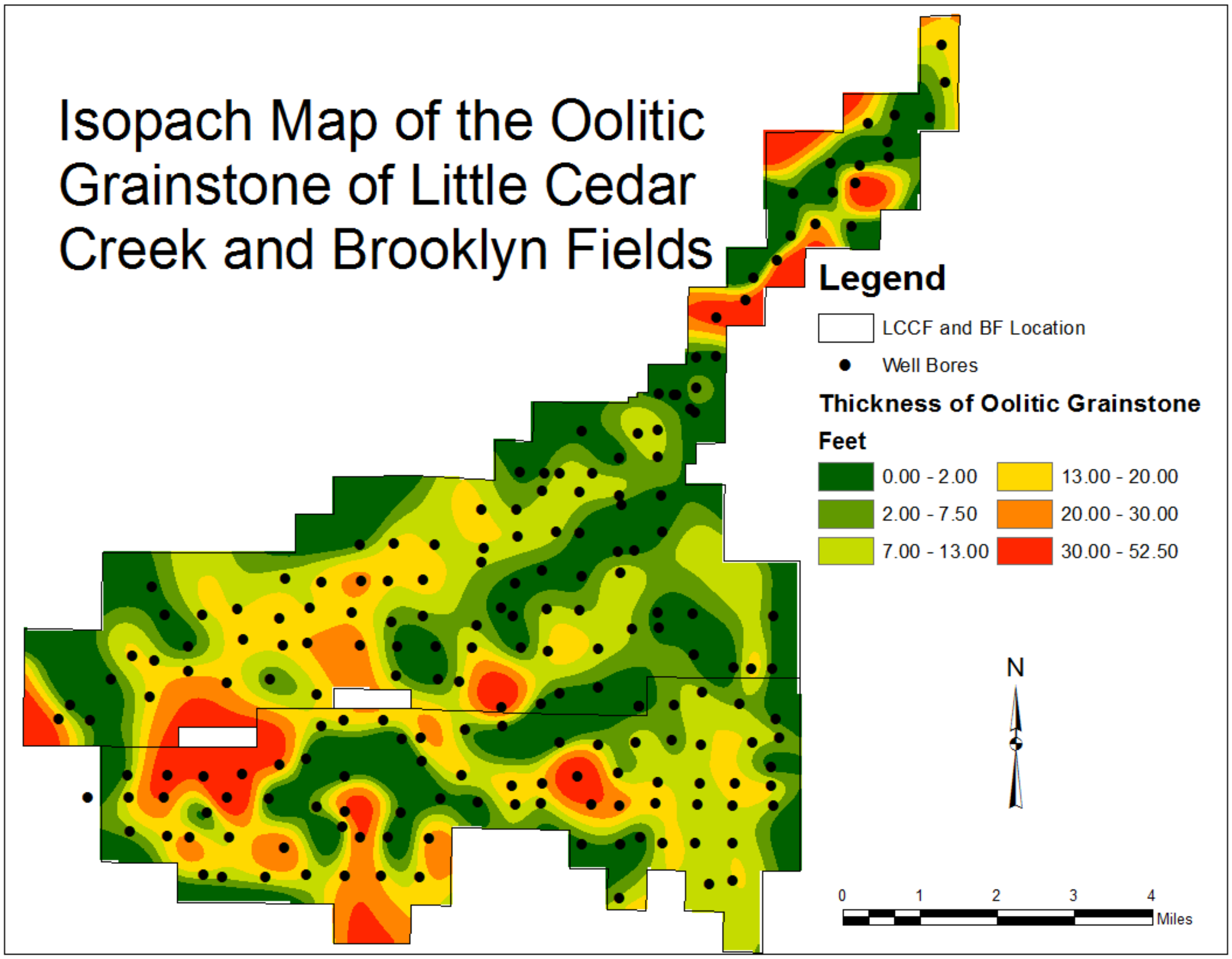


Figure 13. Isopach map of the Oolitic Grainstone in Little Cedar Creek Field and Brooklyn Field

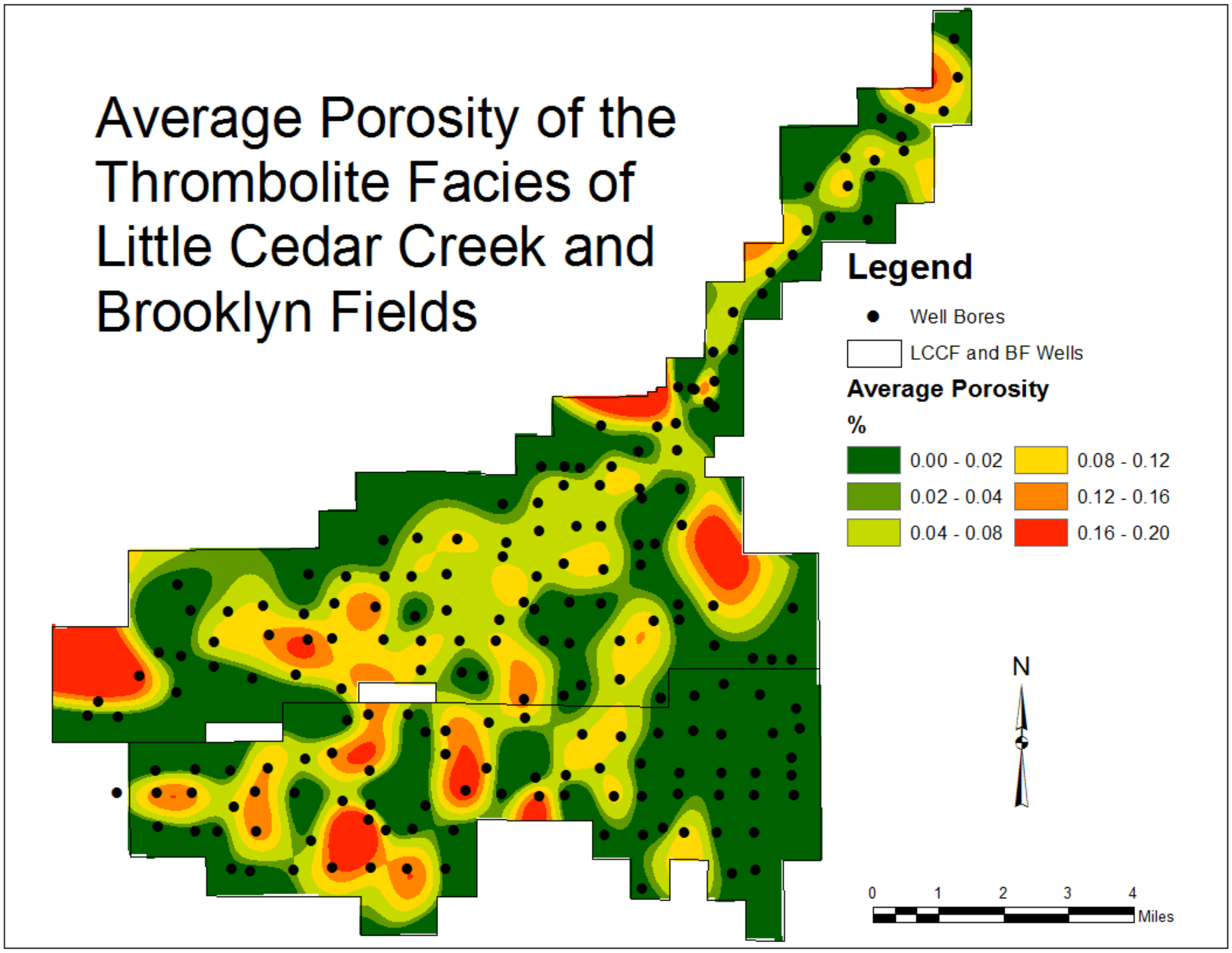


Figure 14. Porosity of the Thrombolite Facies of Little Cedar Creek Field and Brooklyn Field

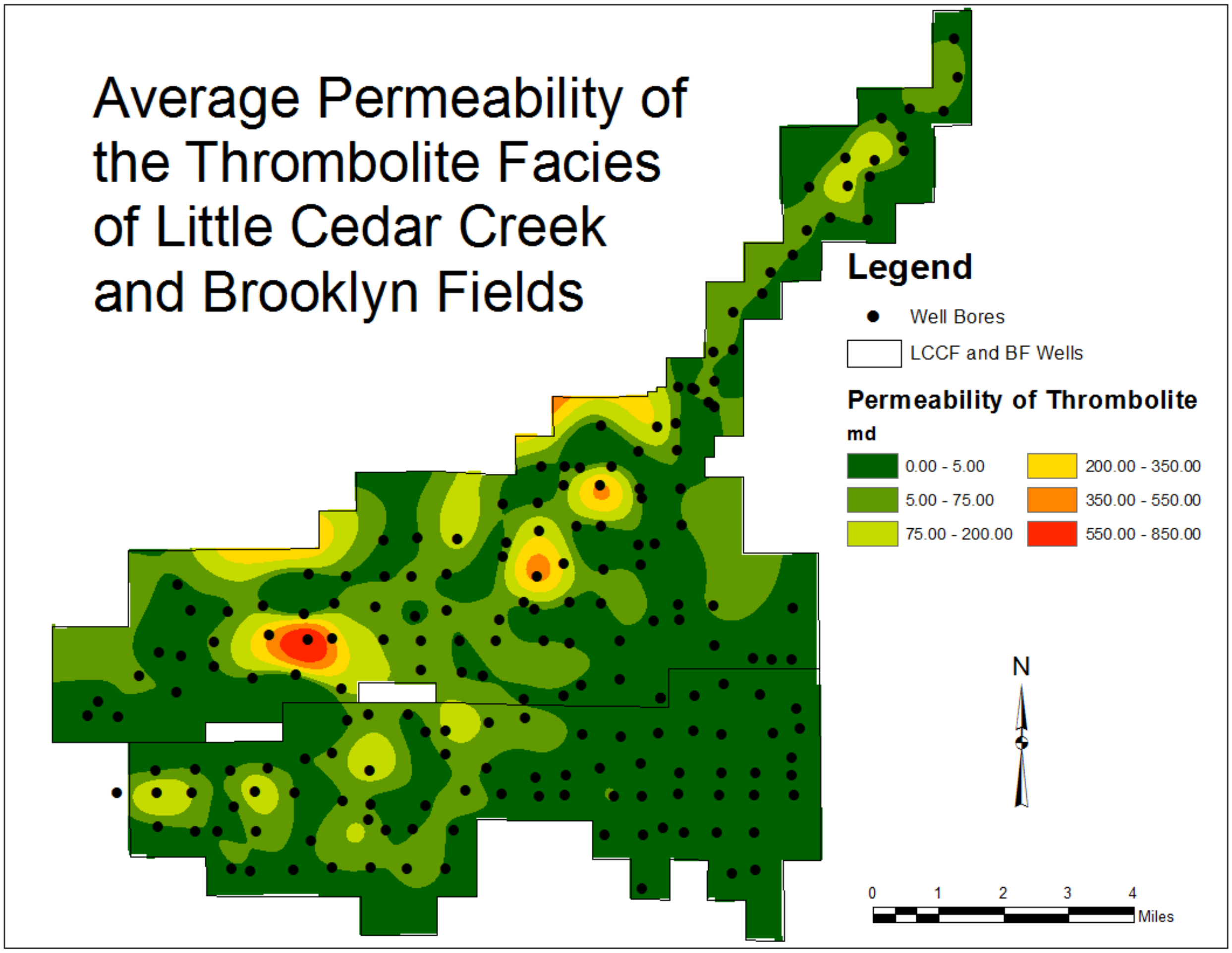


Figure 15. Permeability of Thrombolite Facies of Little Cedar Creek Field and Brooklyn Field

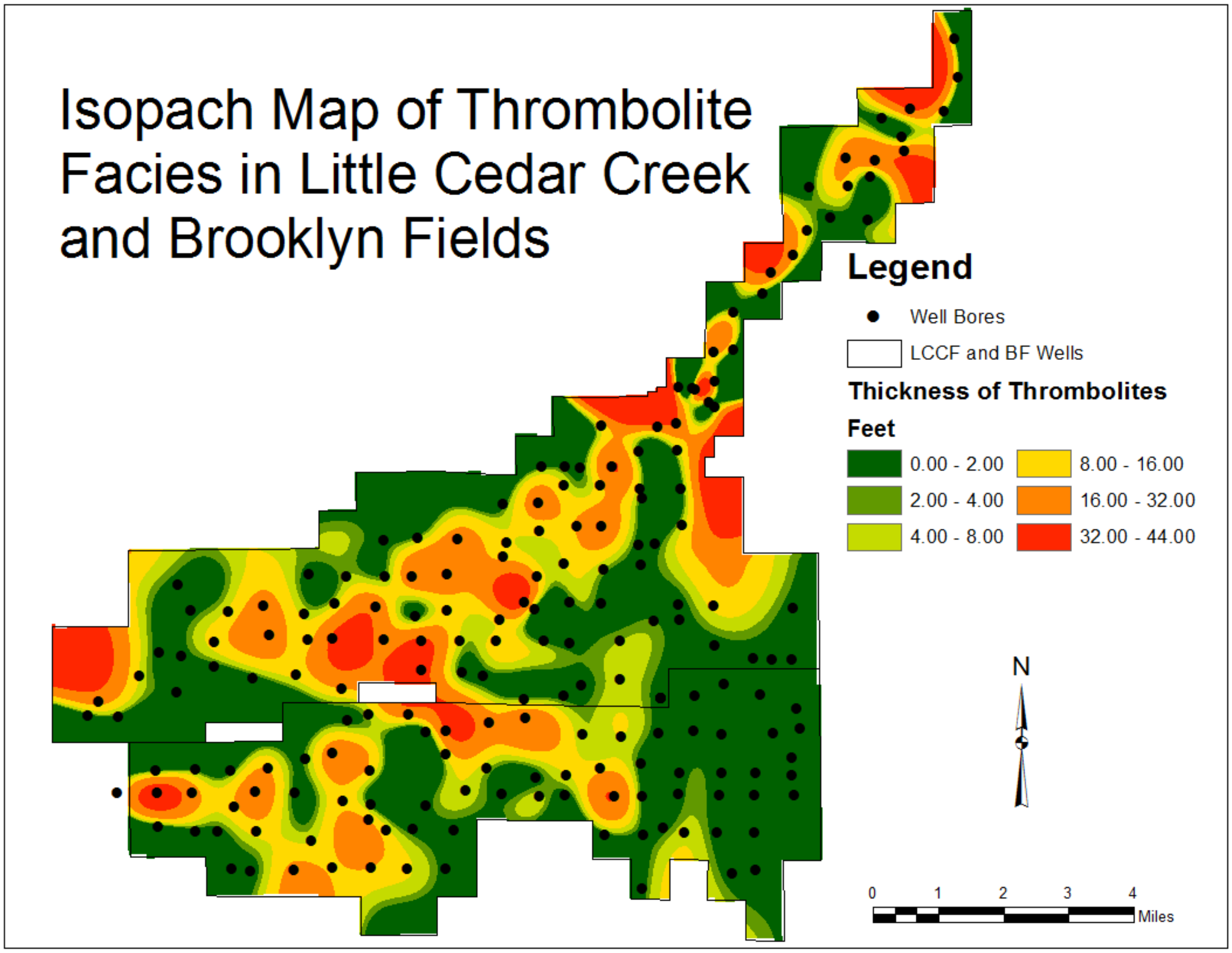


Figure 16. Isopach map of the Thrombolite Facies of Little Cedar Creek Field and Brooklyn Field

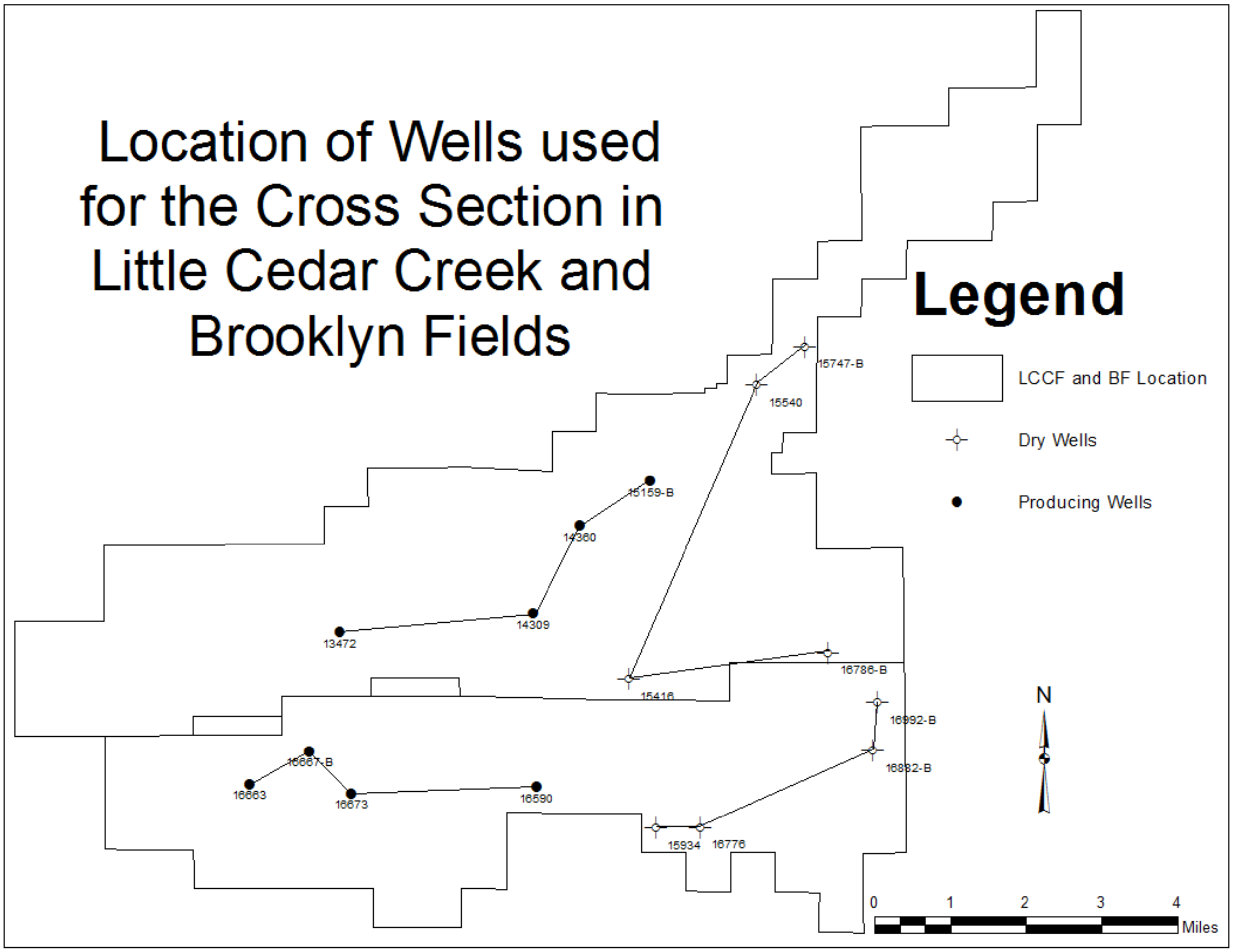


Figure 17. Location of wells used for stratigraphic cross section

CHAPTER 6

RESULTS

The cost per well to run seismic, leases, drilling, complete wells, set up tanks, separators, etc. costs around $1,635,000 (Baria personal communication). An approximate total of $340,080,000 has been spent to complete the 208 wells in both LCCF and BF. Of those 208 wells, 36 of them are non-producing meaning an approximate total of $58,600,000 has been lost. This study constructed porosity, permeability, and isopach maps of the two reservoirs in LCCF and BF in reference to oil and gas production, to see if a correlation could be derived to understand the cause of 36 non-producing wells.

Oolitic Grainstone and Thrombolite Facies

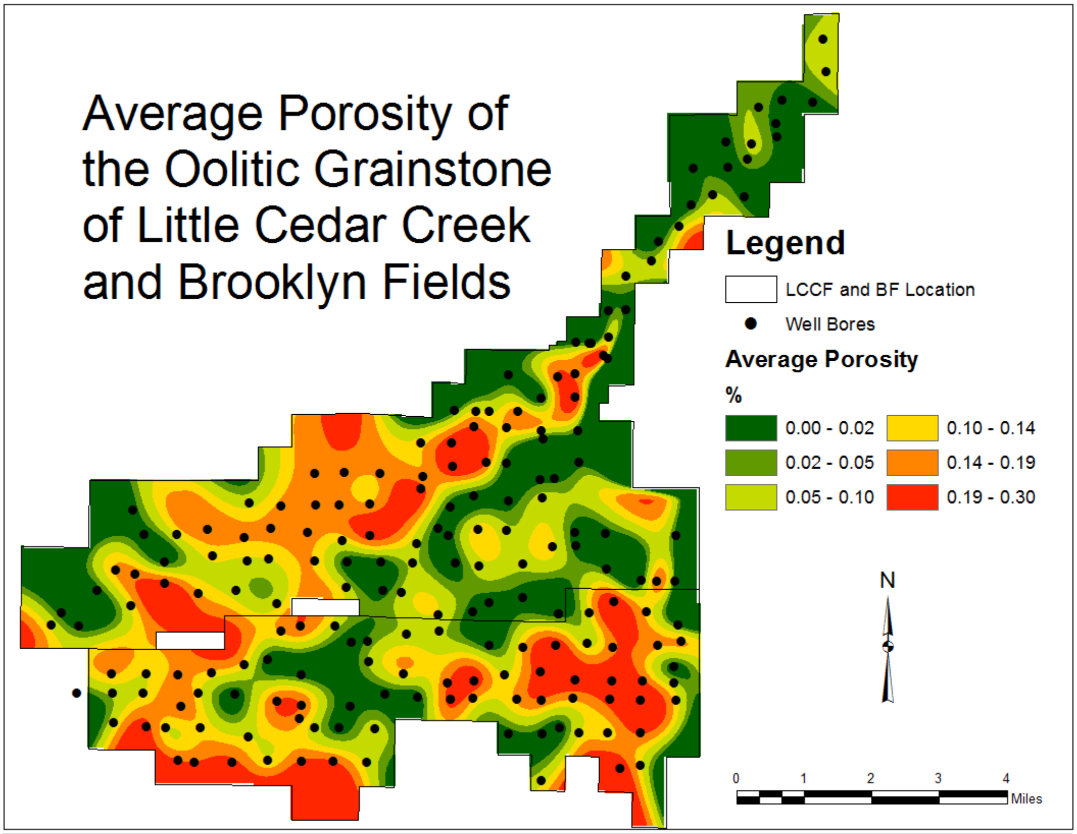
From analyzing the figures of the oolitic grainstone it appears that the thickness of the oolitic facies has a direct affect on porosity and permeability distribution. The thickness of the oolitic grainstone ranges from 2 to 52.50 feet and porosity ranges from (2% to 30%), while the permeability varies from 2 to 250 millidarcy (md). The distribution of oolitic grainstone is in a southwest to northeast trend, with the thickness of the facies decreasing in the eastern and northeastern side of LCCF. The suspected cause of the decrease is the lack of water circulation moving closer to upper edge of the embayment (Tonietto and Pope, 2013).

The thickness in BF exhibits similar characteristics as LCCF, but the grainstone interval stays consistent from a west to east trend with three major buildups (Fig. 18). The isopach map shows the thickness of the grainstone typically ranges between 13 to 52.50 feet and porosity ranges between (10% to 30%). Porosity and thickness of the facies have a direct relationship to oil and gas production and the relationship will be discussed later. The permeability does not follow this same trend, the permeability throughout each field generally ranges from 0 to 30 md, with three areas displaying a higher value ranging from 30-260 md (Fig. 19).

The thickness of the thrombolite facies is not as consistent as the oolitic facies and occurs more in LCCF than in BF. The thickness of the thrombolite facies ranges from 2-44 feet, with the porosity ranging from (2%-20%), while the permeability varies from 5-850md. The variation in thickness of the thrombolites in LCCF is an initial high (16-32 feet) on the southwest end to a low zone and then remains constant all the way to the northeast with occurrences of greater thickness (32-44 feet) and lower thickness (0-2 feet) (Fig. 20). In BF the thrombolite facies thickness follows the same trend as the porosity map (Fig. 21). The porosity of LCCF follows the thickness trends with the highest value beginning at the west (16 to 20%); then an initial low, afterwards the porosity stays relatively constant to the east with minor porosity lows. The permeability of the thrombolite facies follows the same trends of the porosity and thickness. BF permeability does not display the same characteristics as LCCF because the highest permeability is 75-250 md but the permeability of BF was relatively low at 0-5 md. Permeability of LCCF shows one high of 550-850 md beginning on the west side of the field and afterwards stays constant between 5-350 md to the east.

Determination of the relationship of the thickness, porosity, and permeability was not solely based on examination of the figures. Graphs were made to determine if porosity is influenced by the thickness of the lithofacies. Creating these graphs began by cross-plotting the average porosity/permeability values and the thicknesses of the grainstone and thrombolite facies. Scatter plot were created for of the average porosity vs. thickness and a logarithmic scale of the average permeability vs. thickness. A linear trendline was constructed to demonstrate the connections of the data points of the average porosity vs. thickness. Since permeability is an exponential function an exponential trendline was used for the average permeability vs. thickness (Fig. 22-25).

The scatter plots of the oolitic grainstone and thrombolite facies show that porosity is not directly related to the thickness of the oolitic grainstone and thrombolite facies. The slopes of the regression lines do not differ significantly from the mean values. One would expect low thickness to represent low porosity but that is not the case. However, permeability does show a positive relationship to thickness. Even with the increase of thicknesses average porosity values fluctuate between high and low. So when determining oil production of the oolitic grainstone and thrombolite facies the relationship of the porosity, permeability, and thickness of the facies should all be used to evaluate hydrocarbon production.



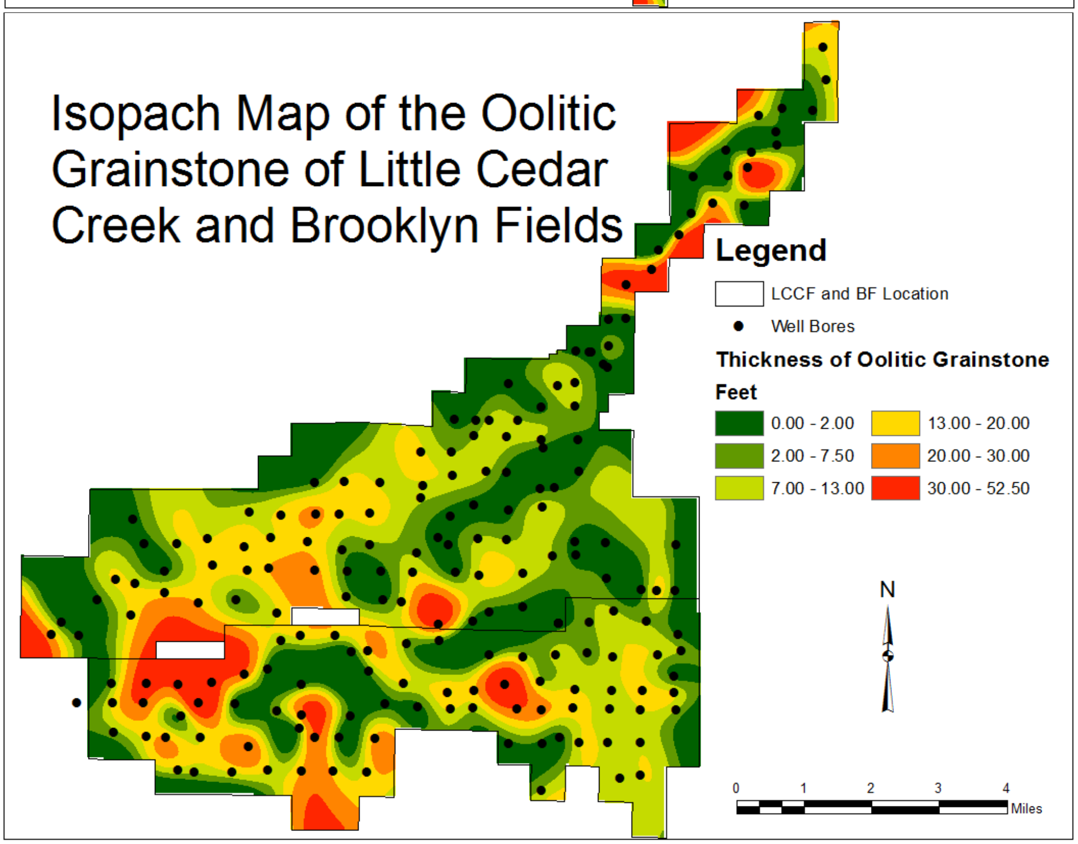


Figure 18. Comparison between the porosity and thickness of the oolitic grainstone of LCCF and BF

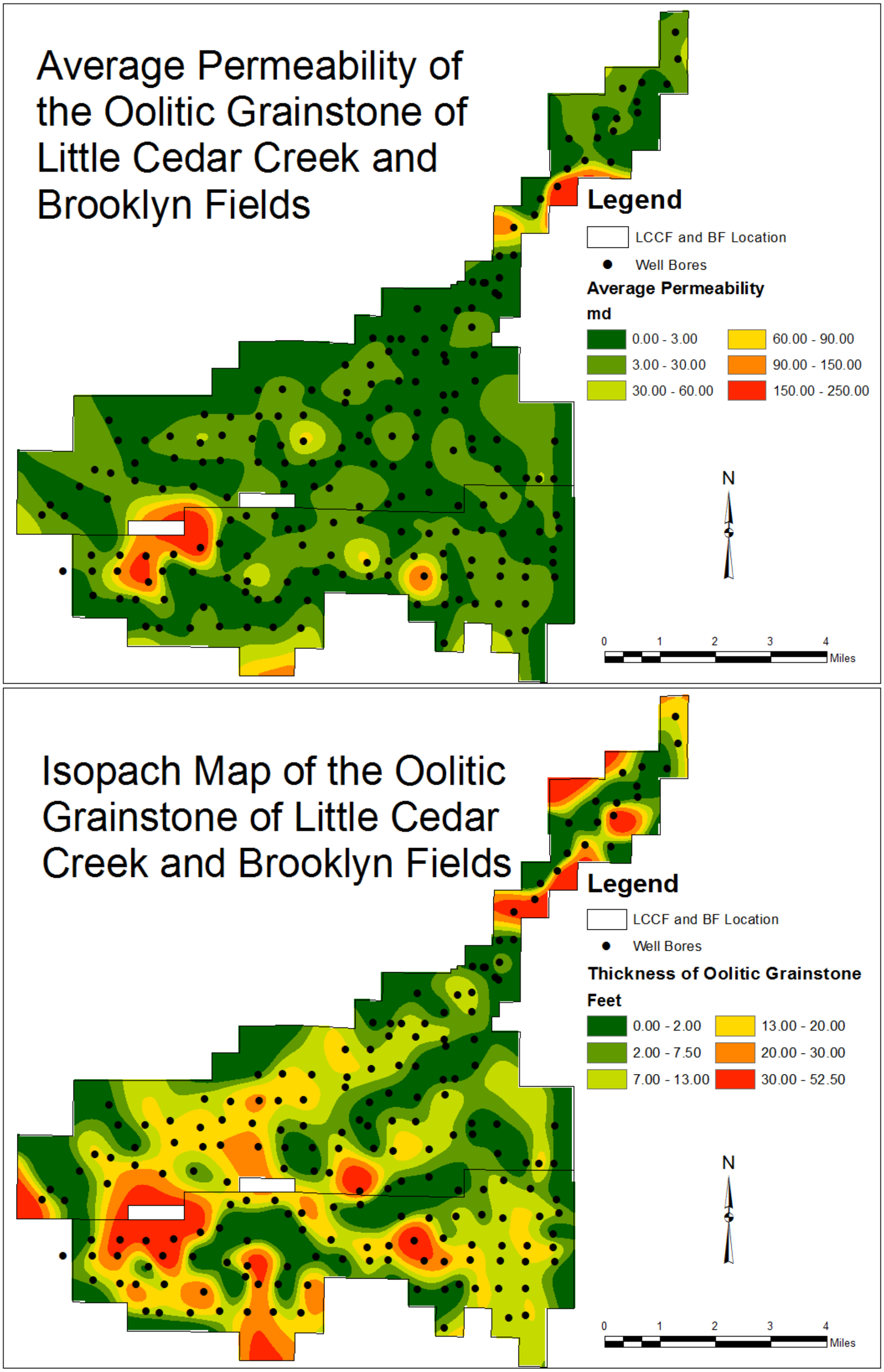


Figure 19. Comparison between the permeability and thickness of the oolitic grainstone of LCCF and BF

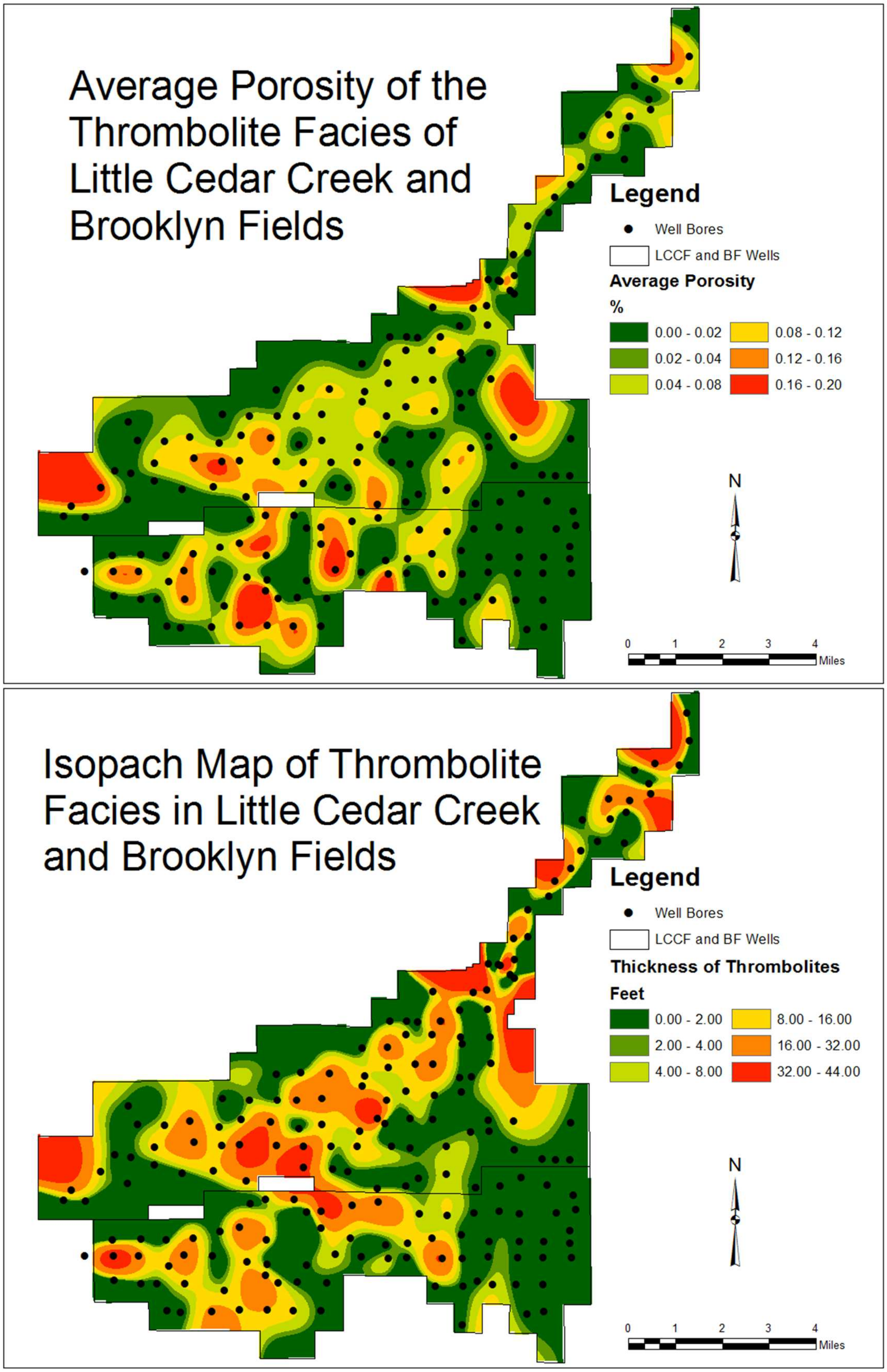


Figure 20. Comparison between the porosity and thickness of the thrombolite facies of LCCF and BF

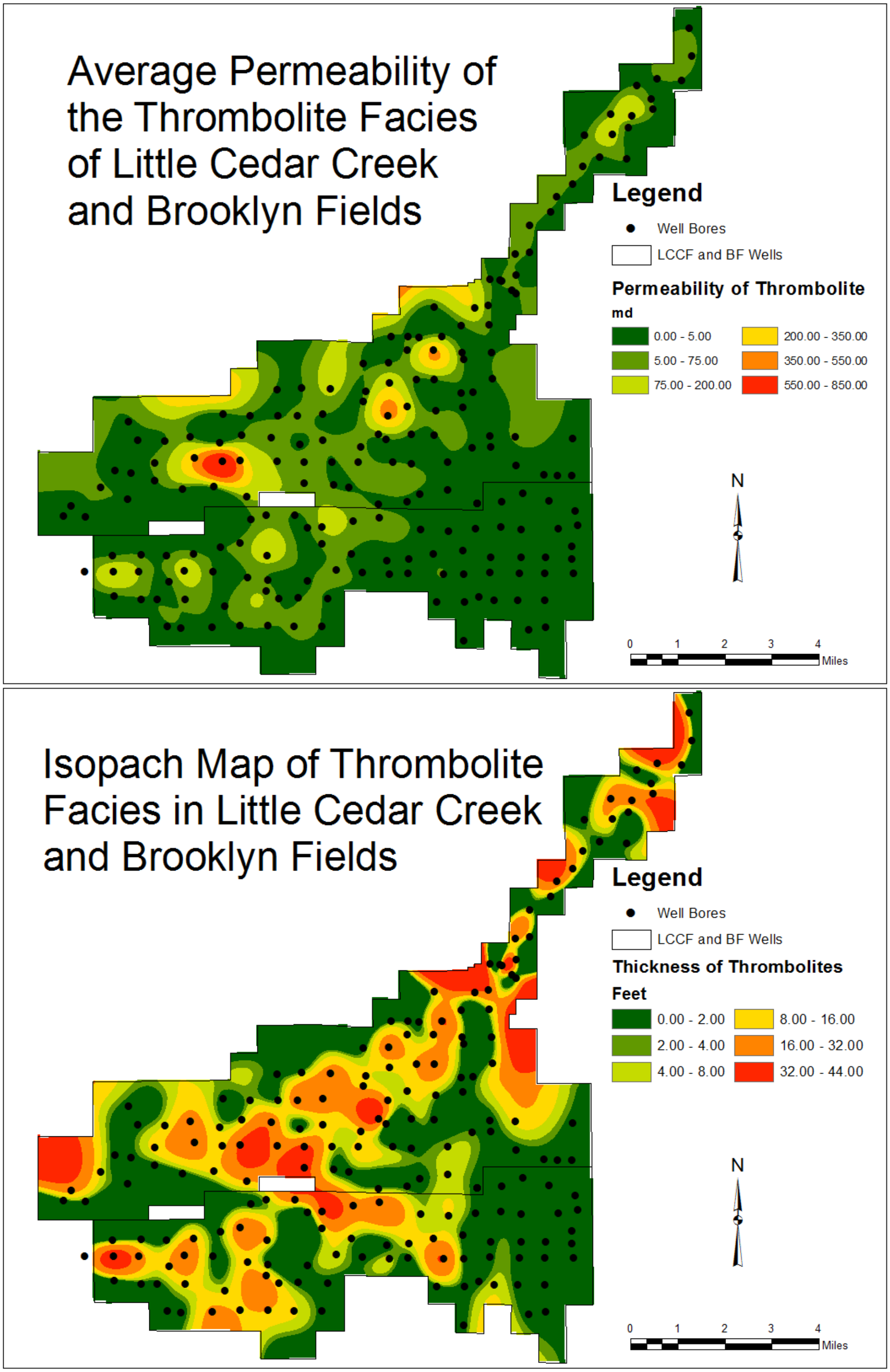


Figure 21. Comparison between the permeability and thickness of the thrombolite facies of LCCF and BF

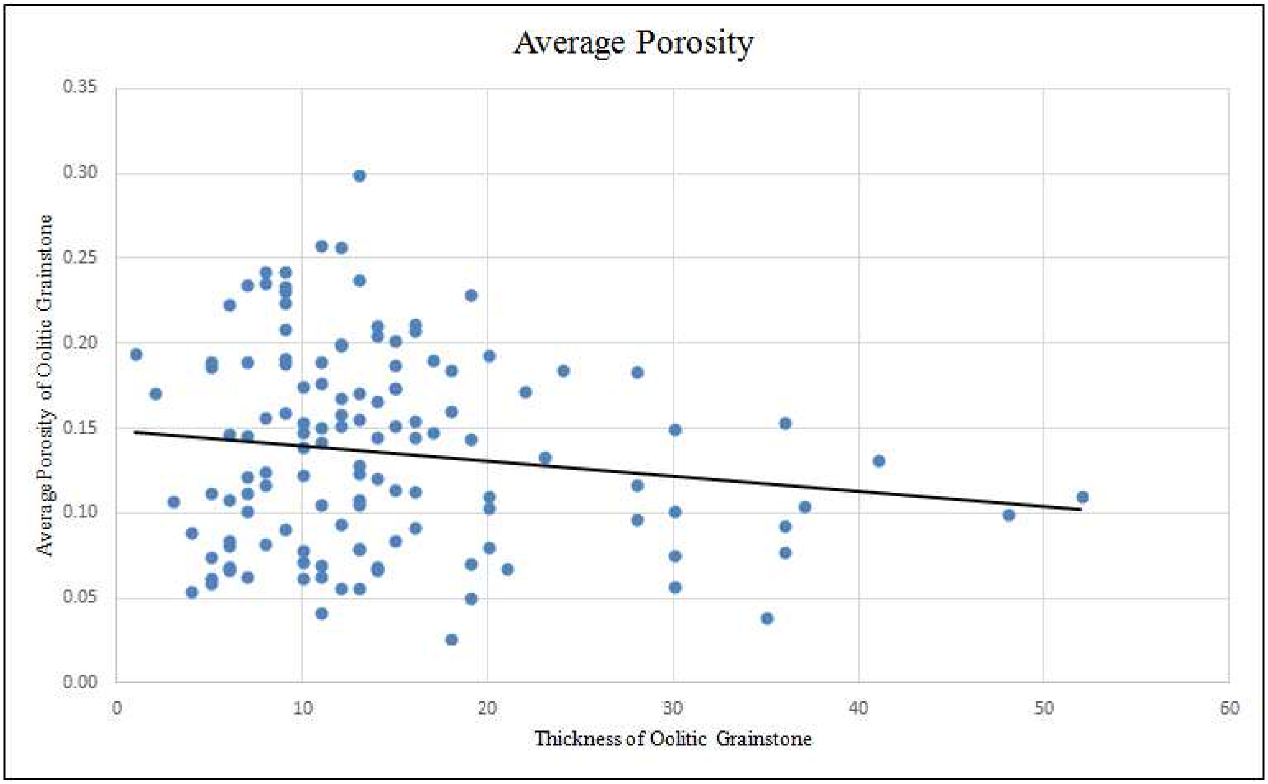


Figure 22. Relationship of the average porosity and thickness of the oolitic grainstone using a linear trendline

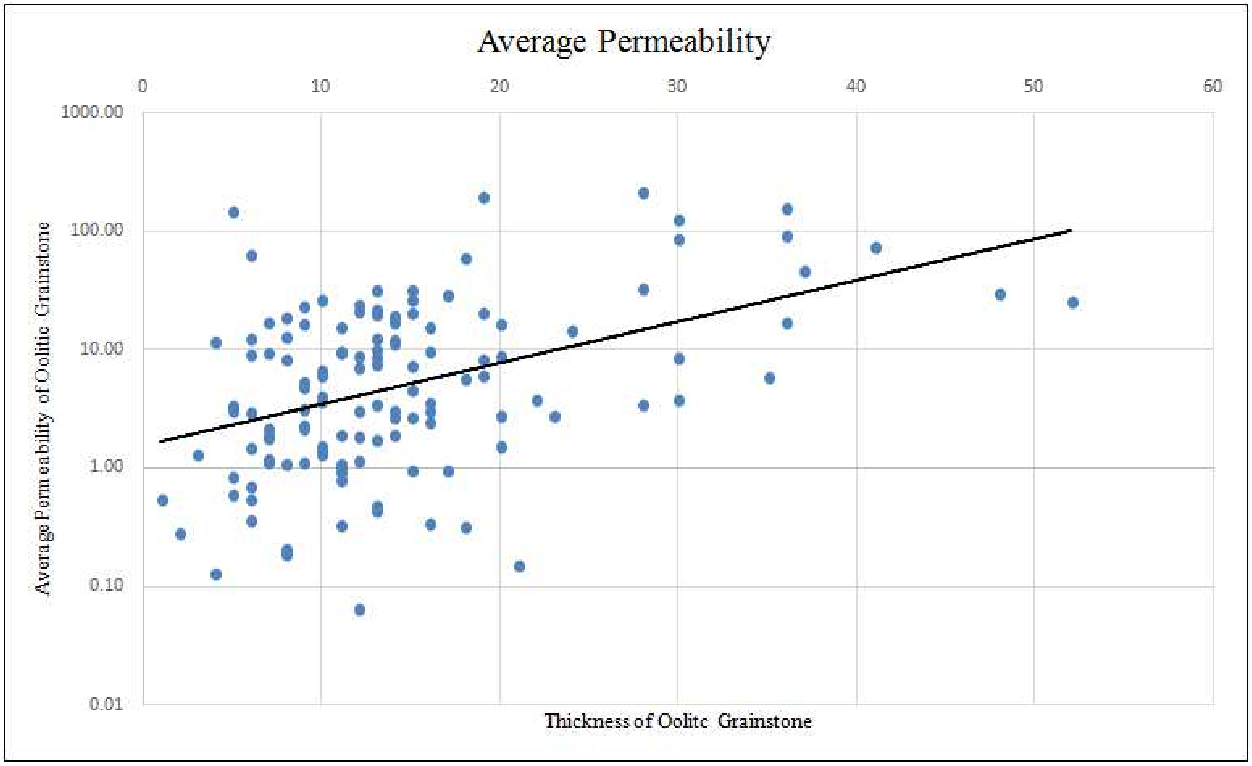


Figure 23. Relationship of the average permeability and thickness of the oolitic grainstone using an exponential trendline

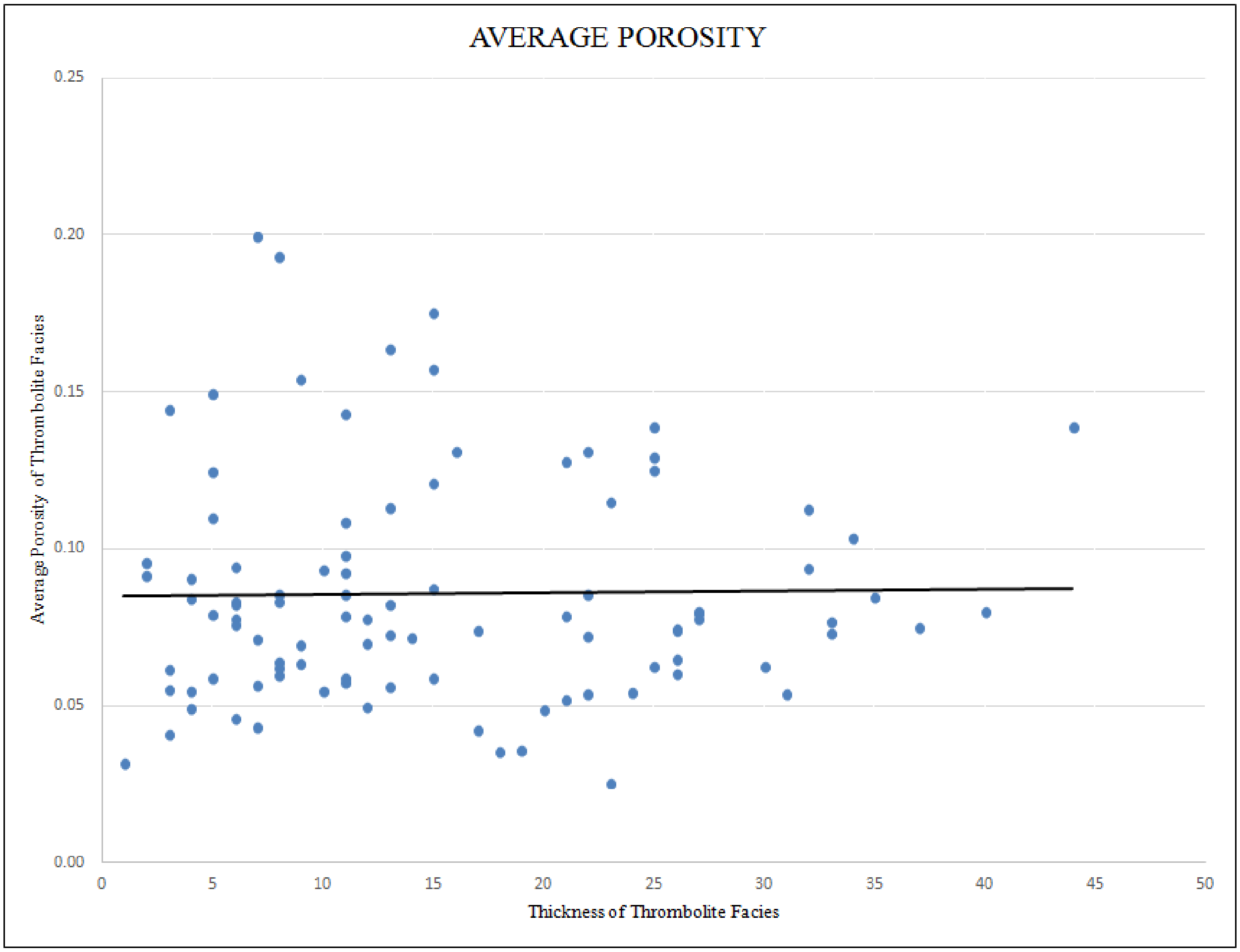


Figure 24. Relationship of the average porosity of the thrombolite facies vs. thrombolite thickness using a linear trendline

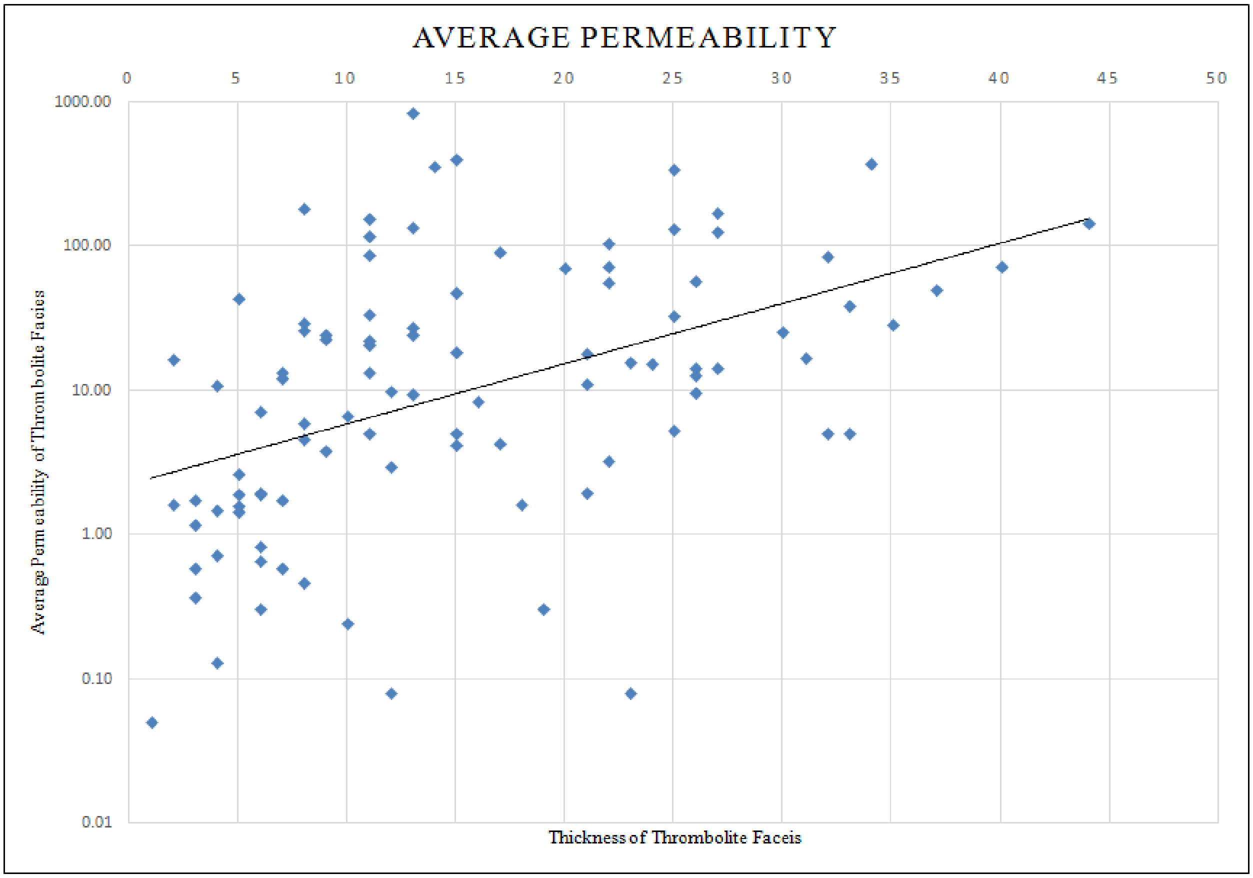


Figure 25. Relationship of the average permeability of thrombolite facies vs. thrombolite thickness using an exponential trendline

Porosity, Permeability, and Hydrocarbon Production

Average porosity was then compared to oil and gas production to see if a correlation could be depicted. The oil production data is current to May 2015 with one well producing as much as 863,200 Bbl and 1,349,220 BCF since production began in LCCF and BF. Oil and gas production of LCCF and BF have the same general trend. Porosity of the oolitic grainstone influences oil and gas production but there is not a direct correlation between the figures because in some areas of both fields low porosity zones show high productive zones. Little Cedar Creek Field hydrocarbon production and porosity zones of the oolitic grainstone appear to have the same relationship in the western and central portion. Where the porosity values are higher the oil and gas production of those wells are generally higher and vice versa. However, this is not the case beginning to the northeastern part of the field which reveals a lower porosity value (0% - 20%), but has producing wells that have totaled over 270,000 Bbl and 370,000 BCF (highly productive wells). In BF where the ooid grainstone occurs, hydrocarbon production stays constant in BF except for initial lows on the western side of the field, the top/bottom of the central portion and small areas on the eastern side.

The thrombolite facies is less porous than the ooid grainstone and is better developed in LCCF than BF. The thickness of the thrombolite boundstone in LCCF stays constant from the southwest to the northeast side of the field, unlike the ooid grainstone on the northeastern side of LCCF. However, in BF the majority of the western side of the field porosity of thrombolite is (0% -2%) (Fig. 26) and the thickness is 0 to 2 feet (Fig. 25) suggesting that porosity and thickness of the thrombolites may have minimal to no influence on production on this portion of the field.

In addition to the influence of porosity, permeability, and thickness hydrocarbon production is also influenced by other factors. This is due to both reservoirs not appearing together in each producing well throughout the Smackover Formation (Fig. 27-28). Because not all wells produce out of both reservoirs (Fig. 29); oil and gas production maps were created for wells that exclusively produced out of the oolitic grainstone, thrombolite facies, and both reservoirs together (30-35).

The figures show that because the oolitic grainstone is the more porous of the two facies; the oolitic grainstone is the more productive of the two. This result was determined by separating production data to each facies separately and combined. The thrombolite facies since May of 2015 has produced a total of 4,972,815 BBL of oil and 6,037,404 BCF of gas compared to the oolitic grainstone that has produced 6,743,337 BBL of oil and 7,766,394 of gas BCF. Dual production of both reservoirs has reached a total of 14,790,249 BBL of oil and 16,516,537 BCF of gas. Dual-production of the reservoirs occurs in both LCCF and BF, with LCCF experiencing more dual production throughout the field than BF. Well bores of the oolitic grainstone occur more in BF than LCCF but production is greater in LCCF with oil production resembling an oolitic tidal bars. Thrombolite production occurs more in LCCF than BF and hydrocarbon production occurs throughout both fields.

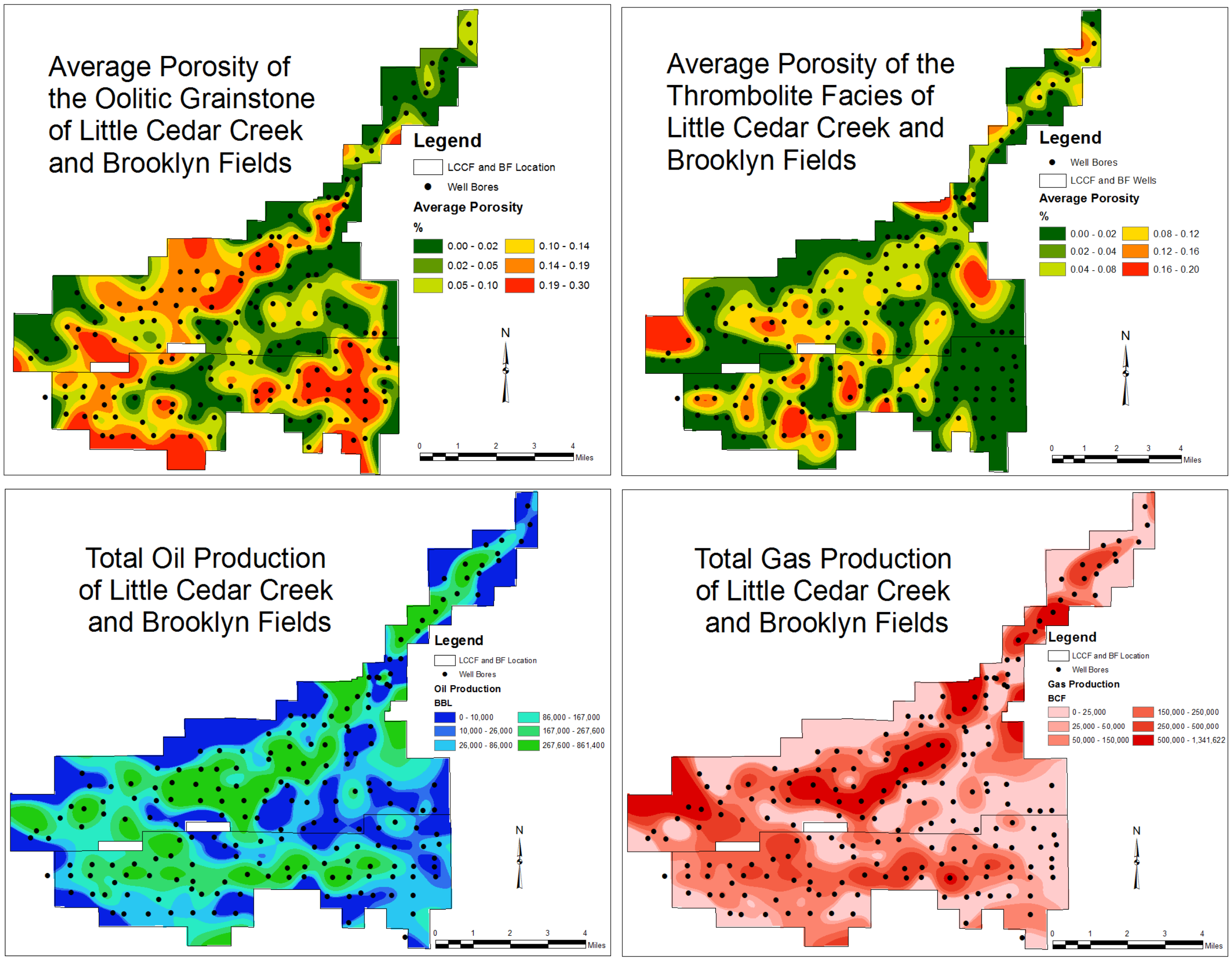


Figure 26. Shows the porosity of the oolitic grainstone and thrombolite facies of LCCF and BF in comparison to oil and gas production

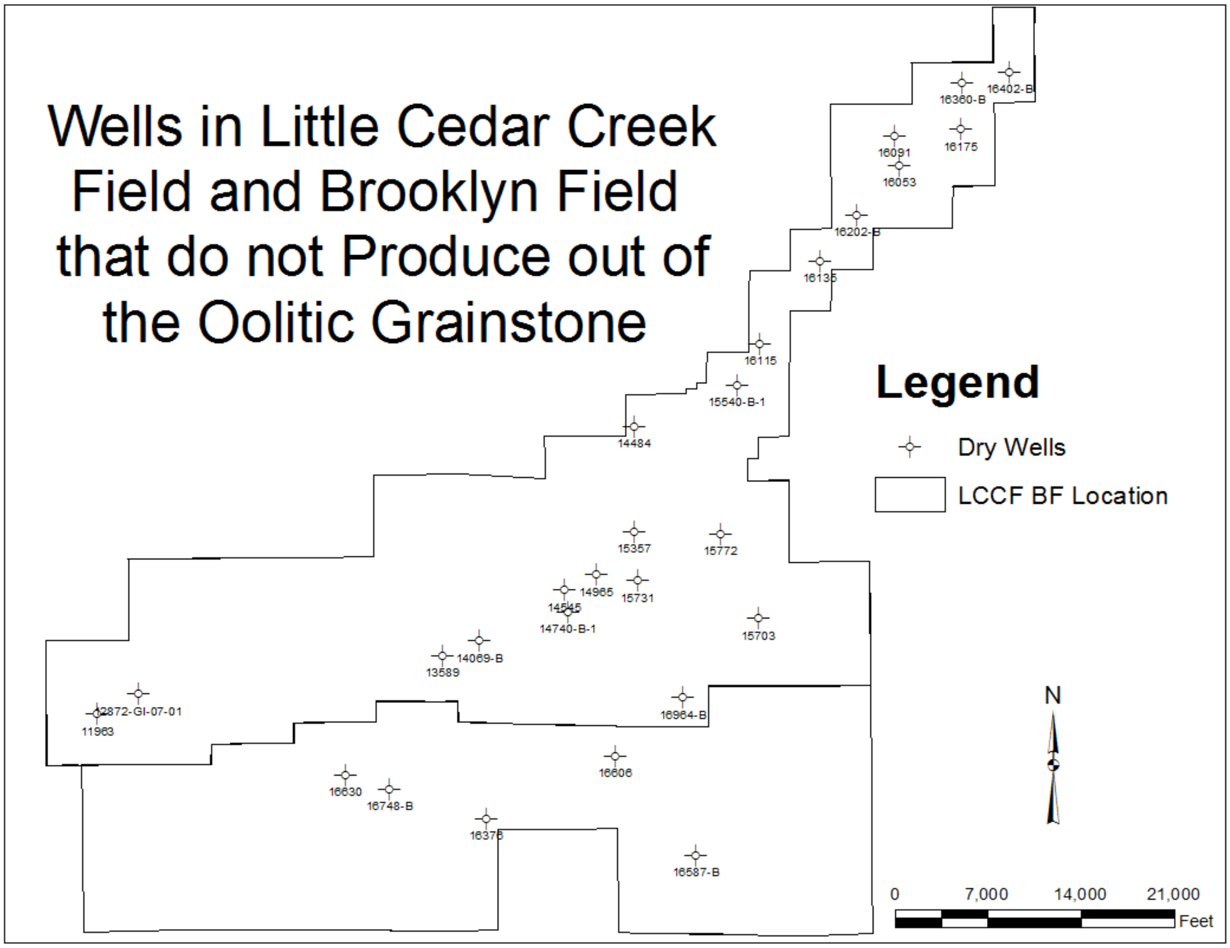


Figure 27. Wells with permit # in Little Cedar Creek and Brooklyn Fields, which do not produce out of the oolitic grainstone (S-3)

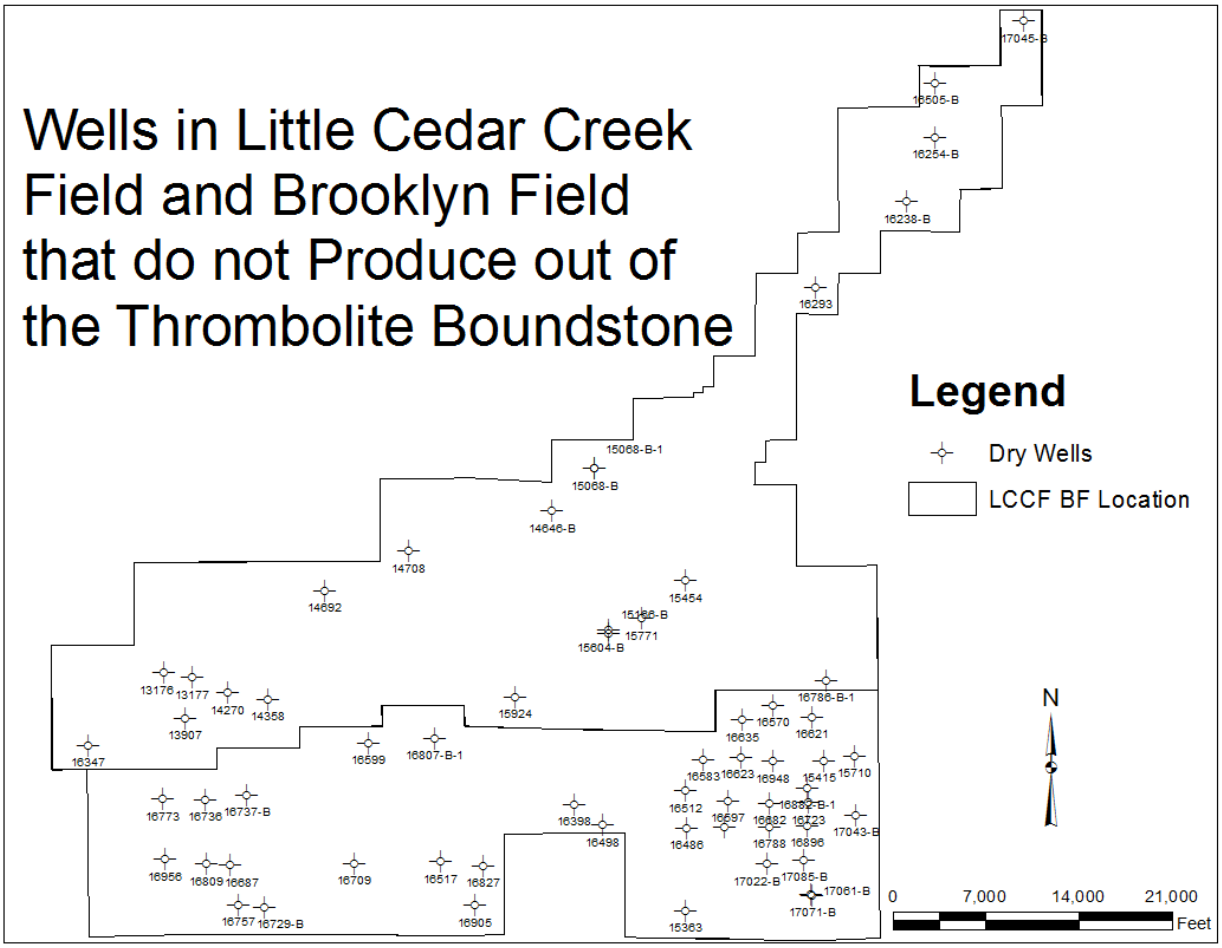


Figure 28. Wells with permit # in Little Cedar Creek Field and Brooklyn Fields, which do not produce out of the thrombolite boundstone (S-6)

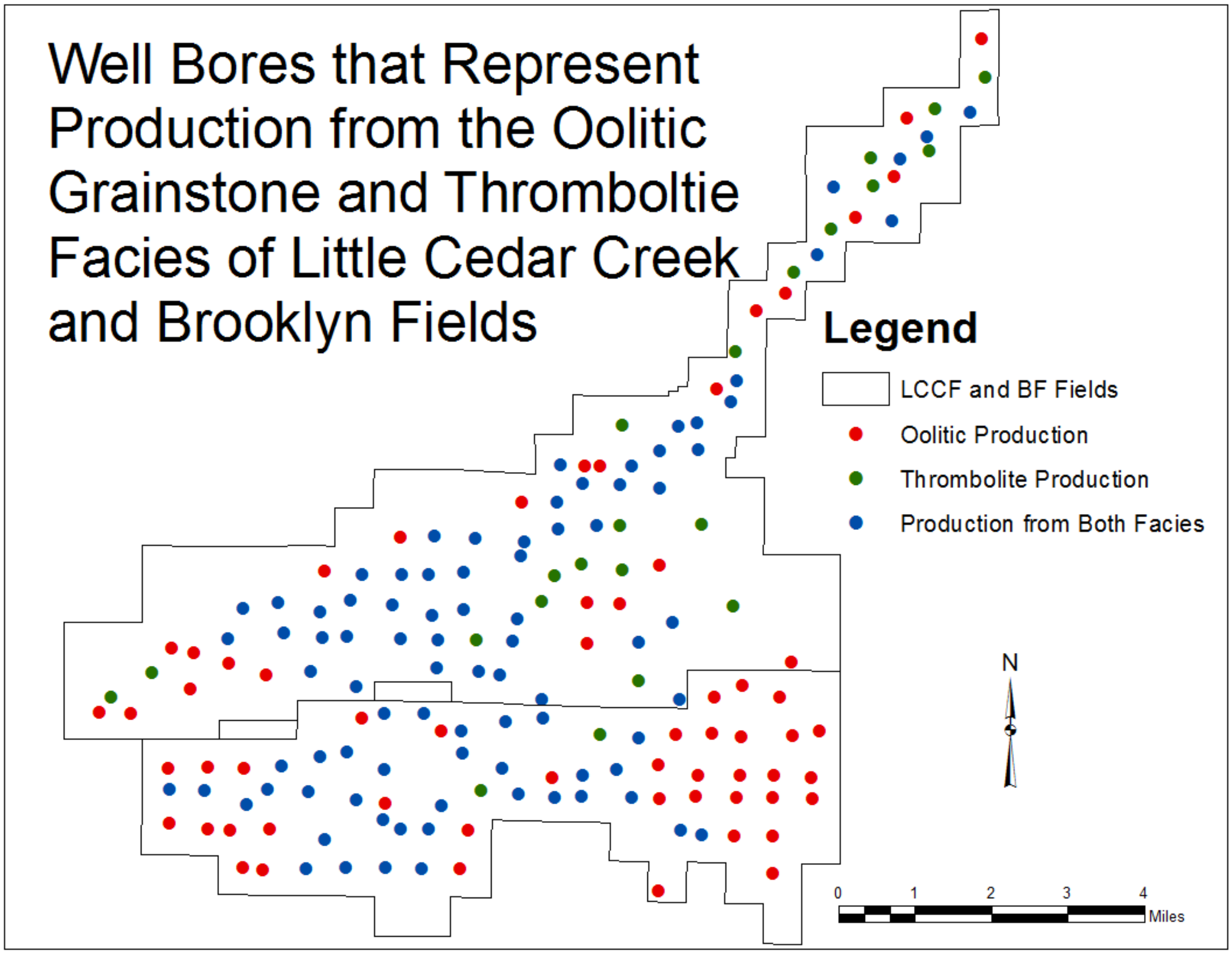


Figure 29. Illustrates the wells bores that either produce out of one of the reservoir facies or both

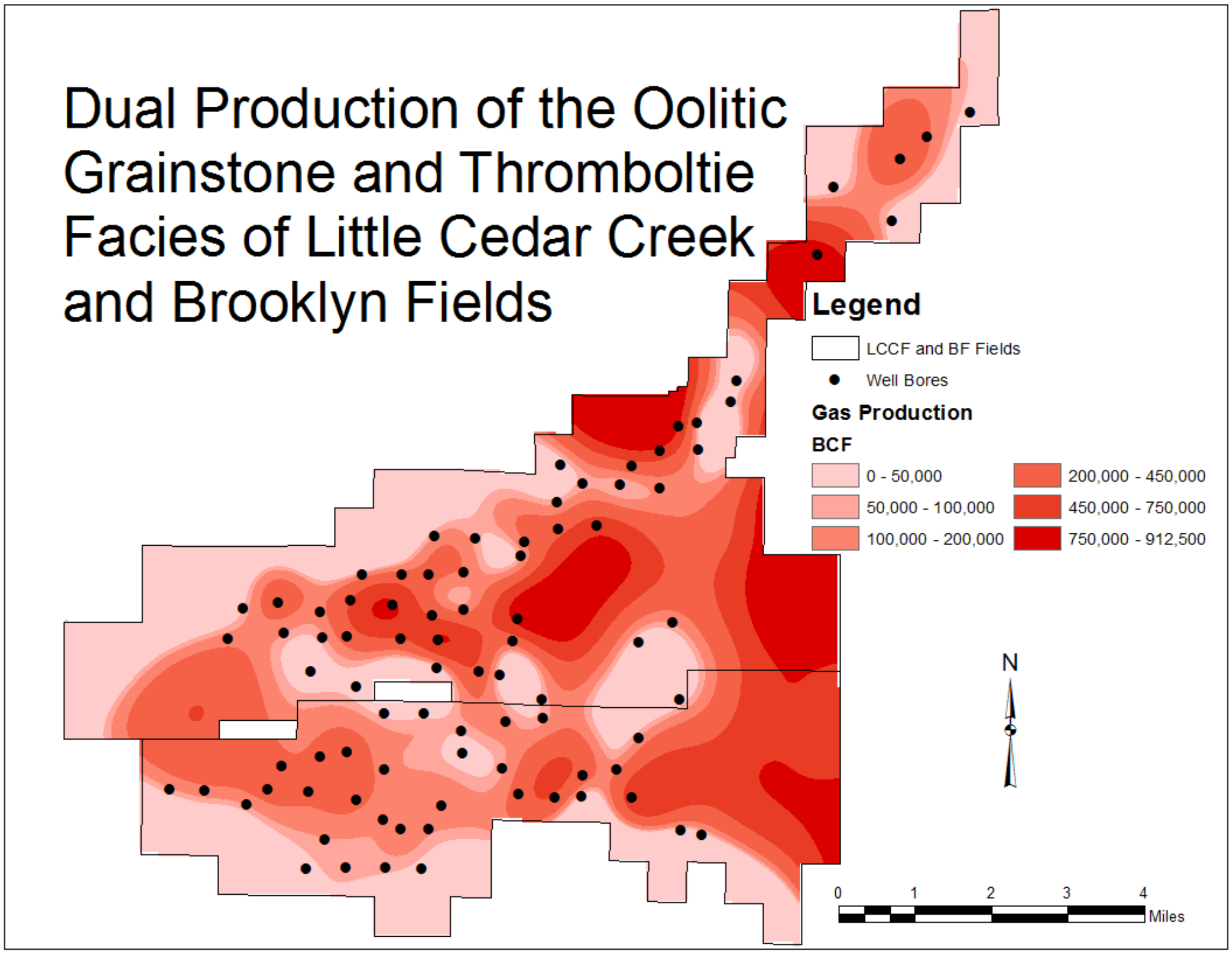


Figure 30. Gas productive wells that produce from both the oolitic grainstone and thrombolite facies

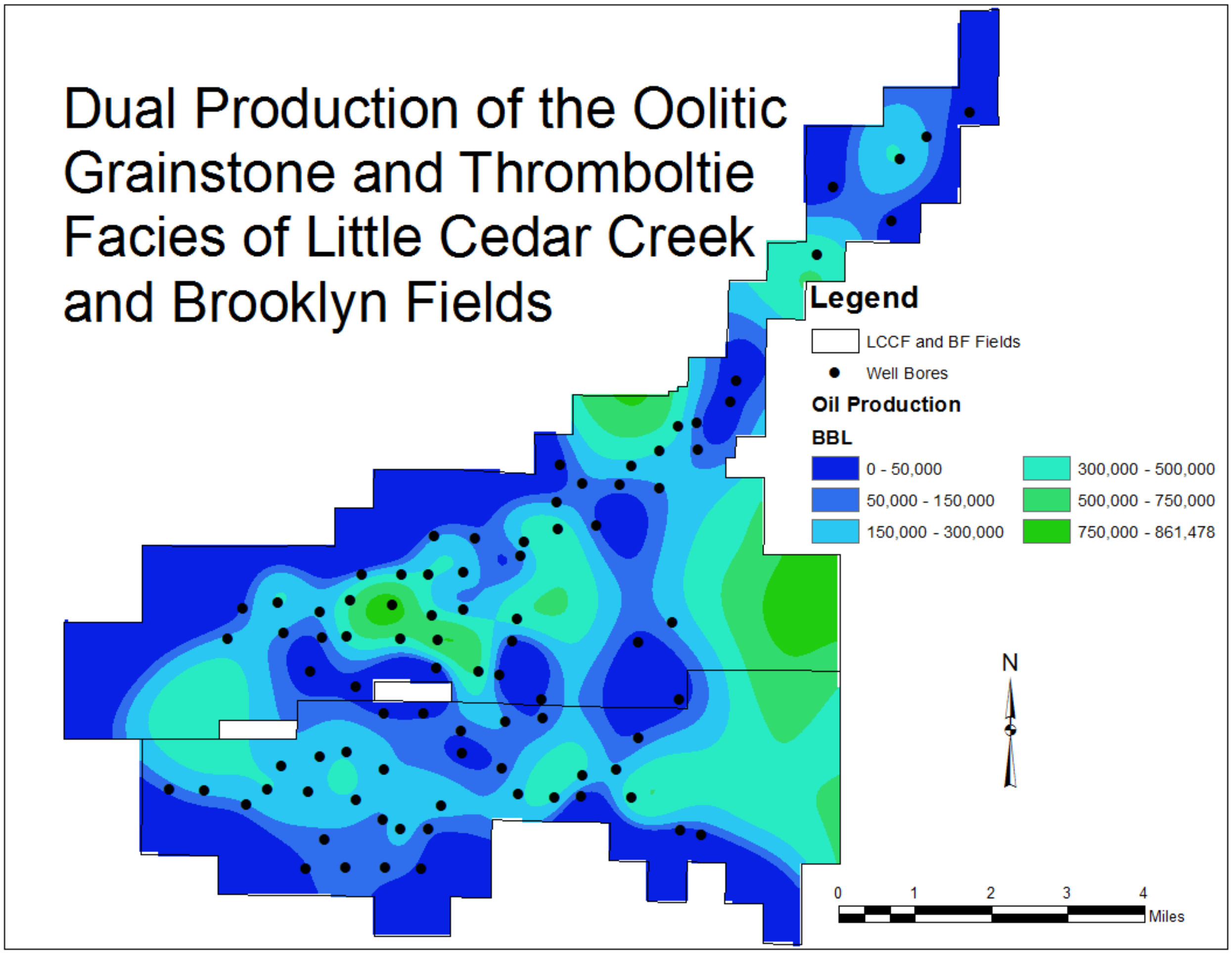


Figure 31. Oil productive wells that produce from both the oolitic grainstone and thrombolite facies

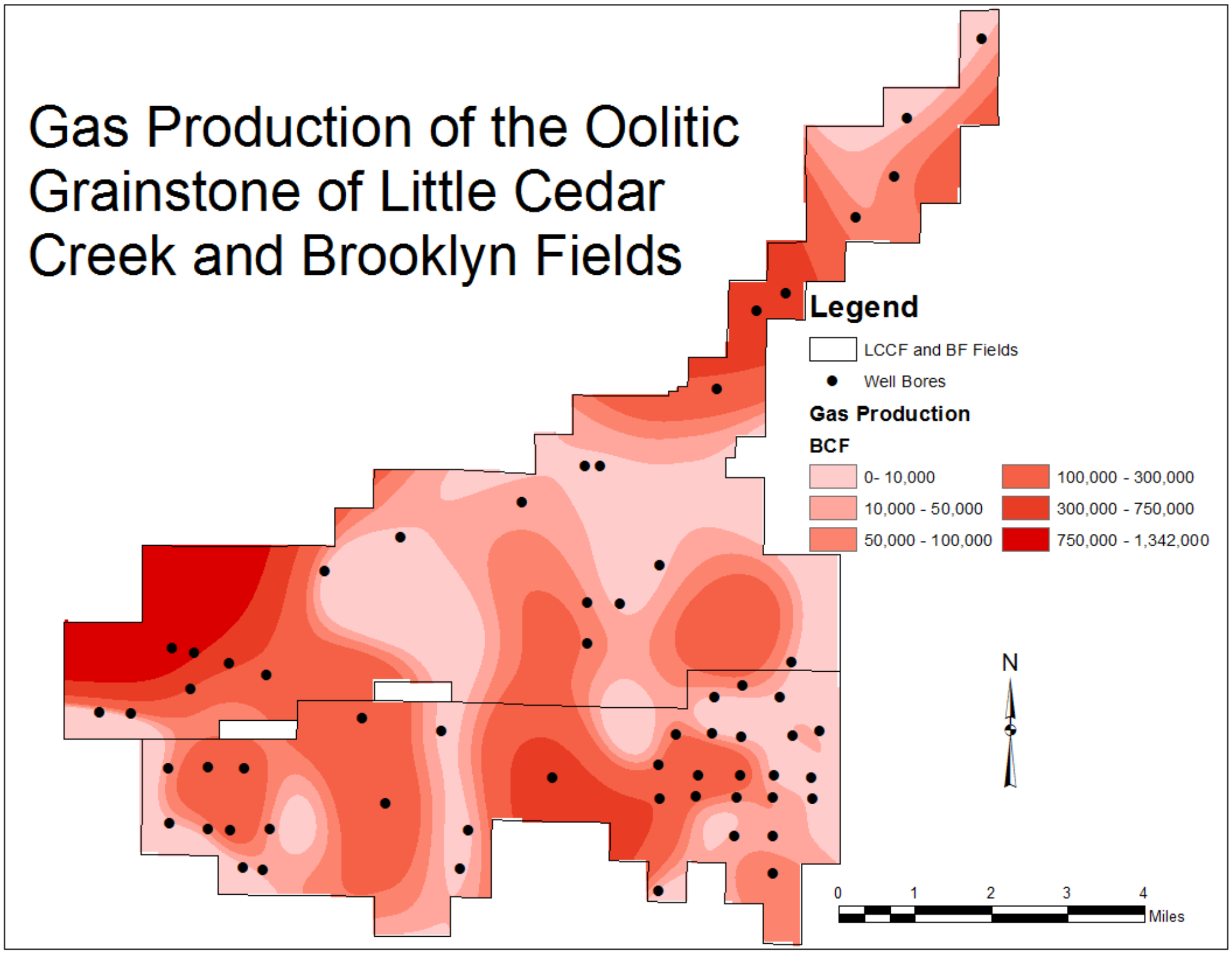


Figure 32. Gas productive wells that produce only out of the oolitic grainstone

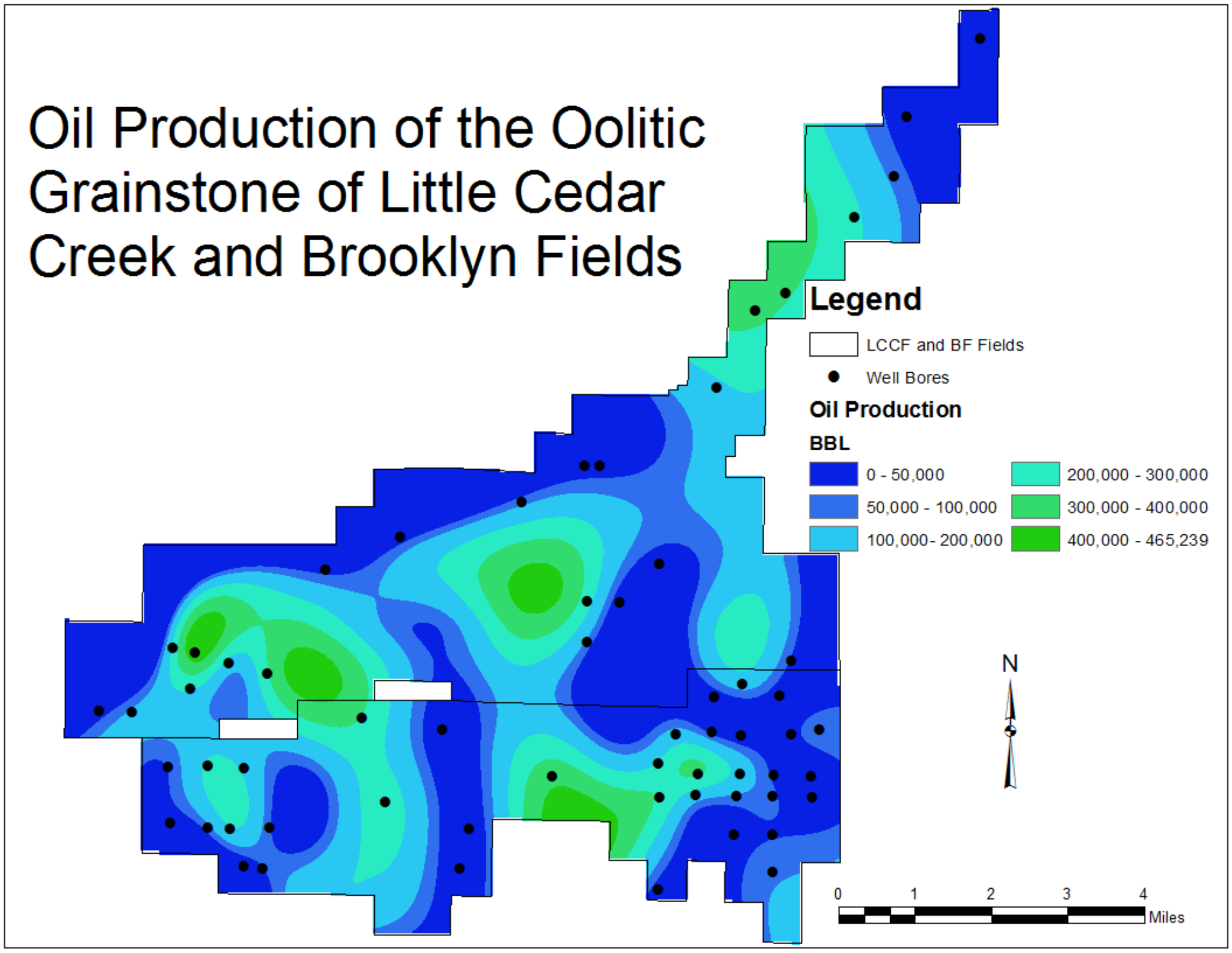


Figure 33. Oil productive wells that only produce out of the oolitic grainstone

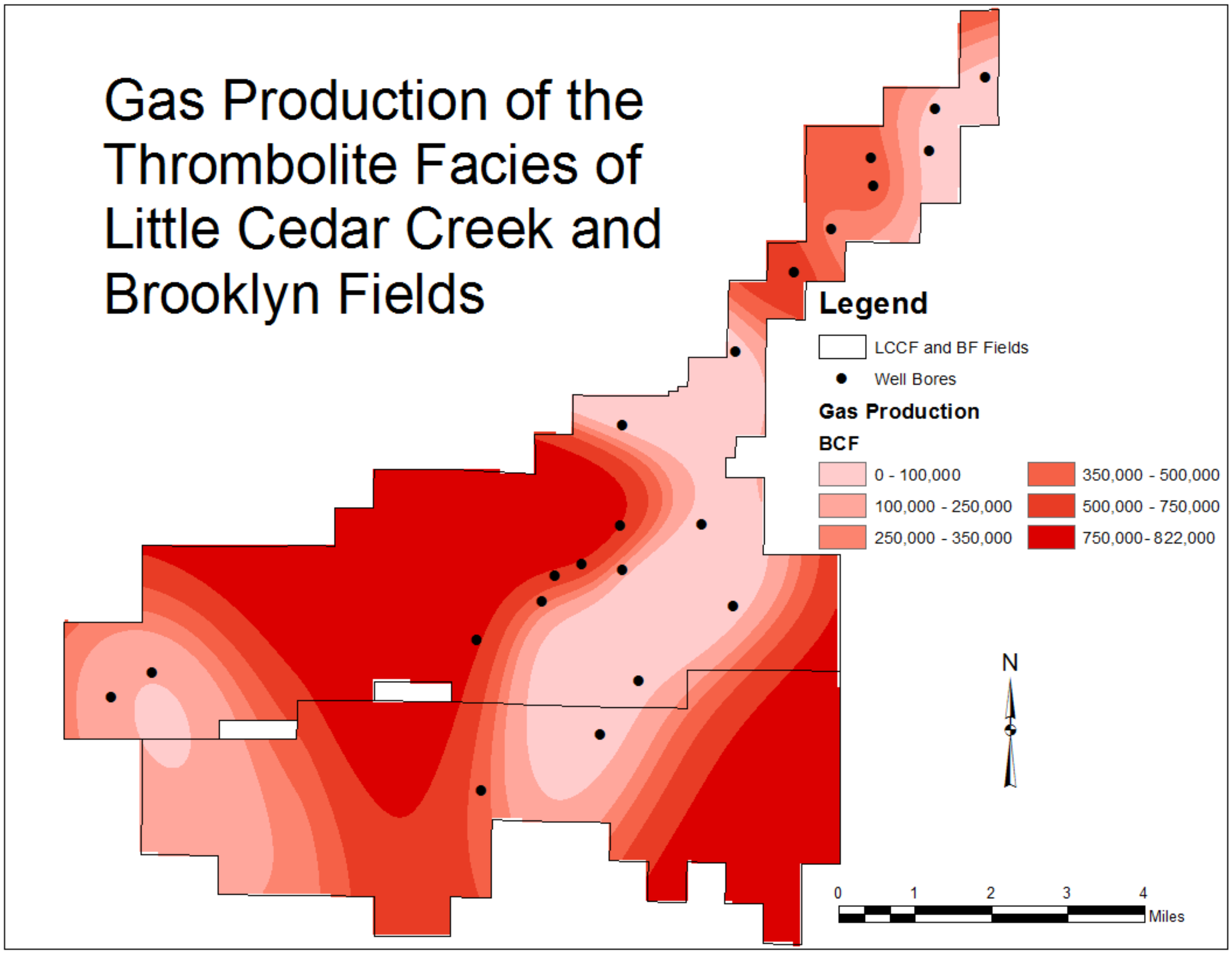


Figure 34. Gas productive wells that only produce out of the thrombolite facies

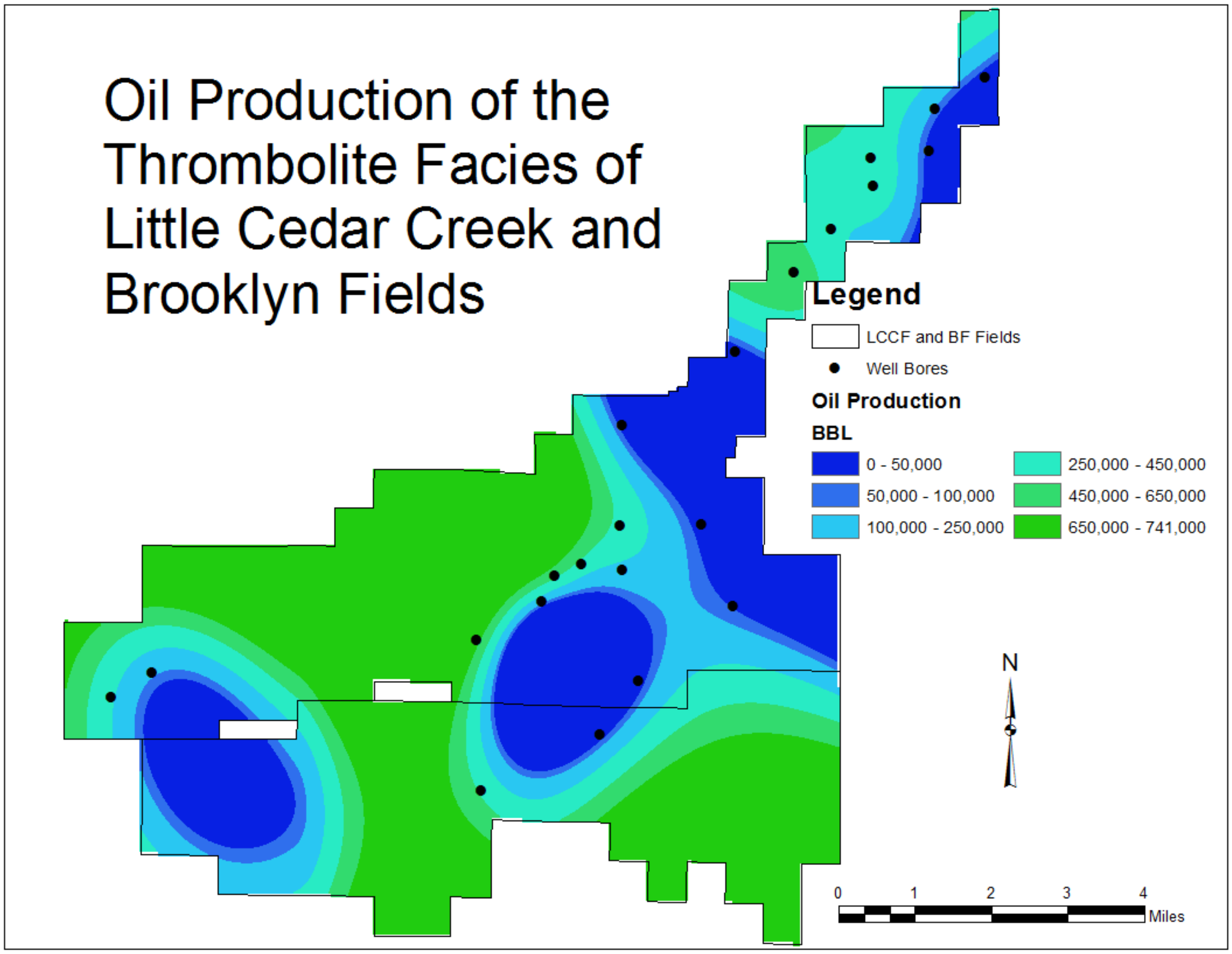


Figure 35. Oil productive wells that produce only from the thrombolite facies

Relationship of Lithofacies

The seven lithofacies within the Smackover Formation were characterized and given different markers to indicate the change of lithology in the well logs (Fig, 36). Ridgway (2010) and Day (2014) stated that when the tidal channel floatstone (S-2) appears it replaces the oolitic grainstone (S-3) reservoir (Fig. 36). Ridgway (2010) and Day (2014) also stated that the S-6 facies (thrombolite boundstone) is better developed when the facies overlying S-5 is under developed and the underlying facies S-7 is thin (Fig. 37).

The ooid grainstone developed during aggradation and progradation of shallow water shoal and tidal-flat complexes during a prolonged sea level highstand and was exposed to meteoric waters in the phreatic zone (Tonietto and Pope, 2013). The exposure to meteoric waters was because the ooid grainstone was terminated by subaerial exposure and this resulted in the formation of the moldic porosity (Heydari and Baria, 2005). Unlike the thrombolite facies the grainstone S-3 is not dependent on paleotopography because its thickness does not correlate to the thickness of the S-4 facies (Day, 2014). The introduction of the tidal conglomerates replaces the shoal grainstone as a result longshore currents that originate on the western side of LCCF and BF. The tidal channel causes the grainstone development to halt (Fig. 38-39). The tidal channel is also believed to have affected deposition and diagenesis, which could have a direct result on hydrocarbon production (Day, 2014).

The thrombolite facies did not develop directly on crystalline rocks or any particular paleohigh, but developed within 3 miles of the Smackover paleoshoreline; thrombolite growth occurred in water depths of less than 10ft (Heydari and Baria, 2005). The laminated mudstone (S-7) was deposited during an early marine transgression and correlates to the thrombolite boundstone because of microbe nucleation on localized firm to hard surfaces associated with wackestone to packstone deposition (Al Haddad and Mancini 2013). The thrombolite facies in LCCF and BF is different from other thrombolites in other Smackover fields. 1. The reservoir is not intensely or totally dolomitized; 2. It displays depositional microtexture, primary porosity features, and pre-dolomitization diagenetic features are preserved (Llinas et al., 2002; Petta and Rapp, 1990). In other the fields the facies is highly leached and the pore types are mainly diagenetic rather than depositional (Heydari and Baria 2005). The thrombolite facies developed during the early stages of a marine transgression and began to terminate because of the reduction in the rate of sea level rise and an influx of freshwater. The relationship of the S-7 facies and the S-6 facies is show in the (Fig. 40-41).

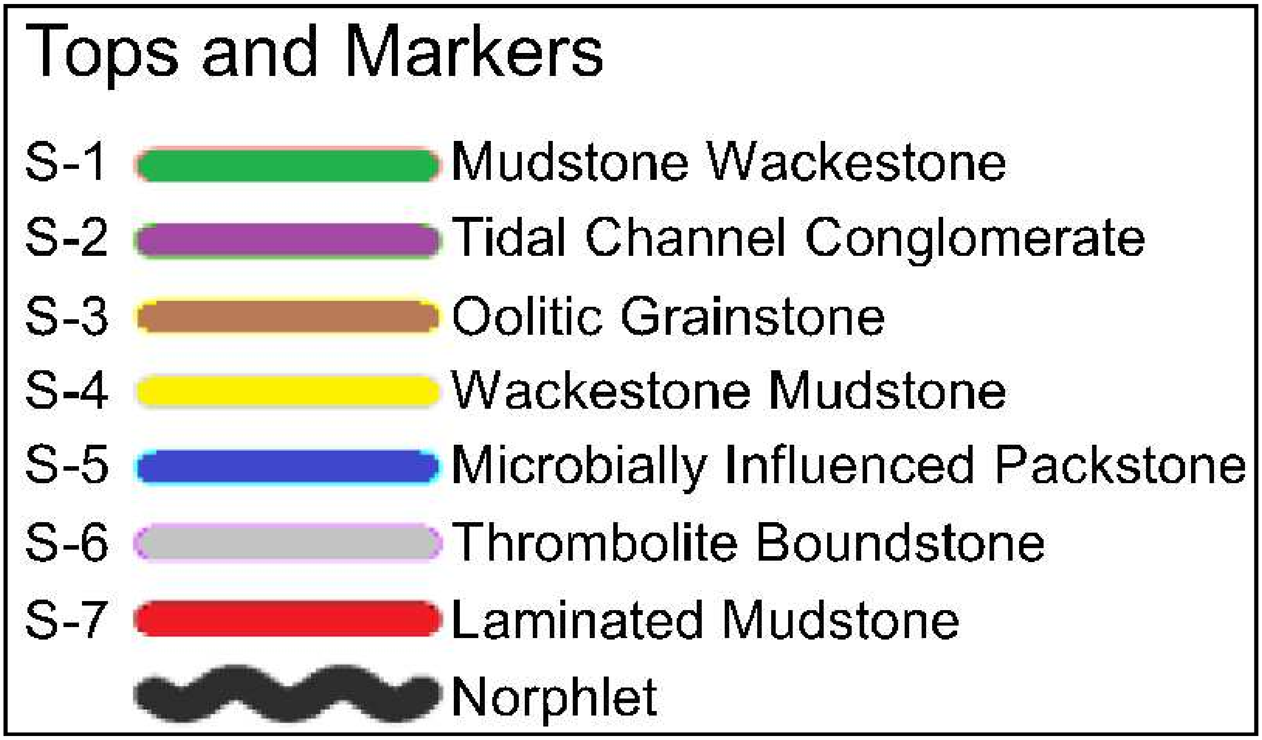


Figure 36. Categorizes the seven different lithofacies within the Smackover Formation that are used for the stratigraphic cross section of Little Cedar Creek and Brooklyn Fields. Note the green is the contact between the Smackover and Norphlet Formations (modified from Ridgway, 2010)

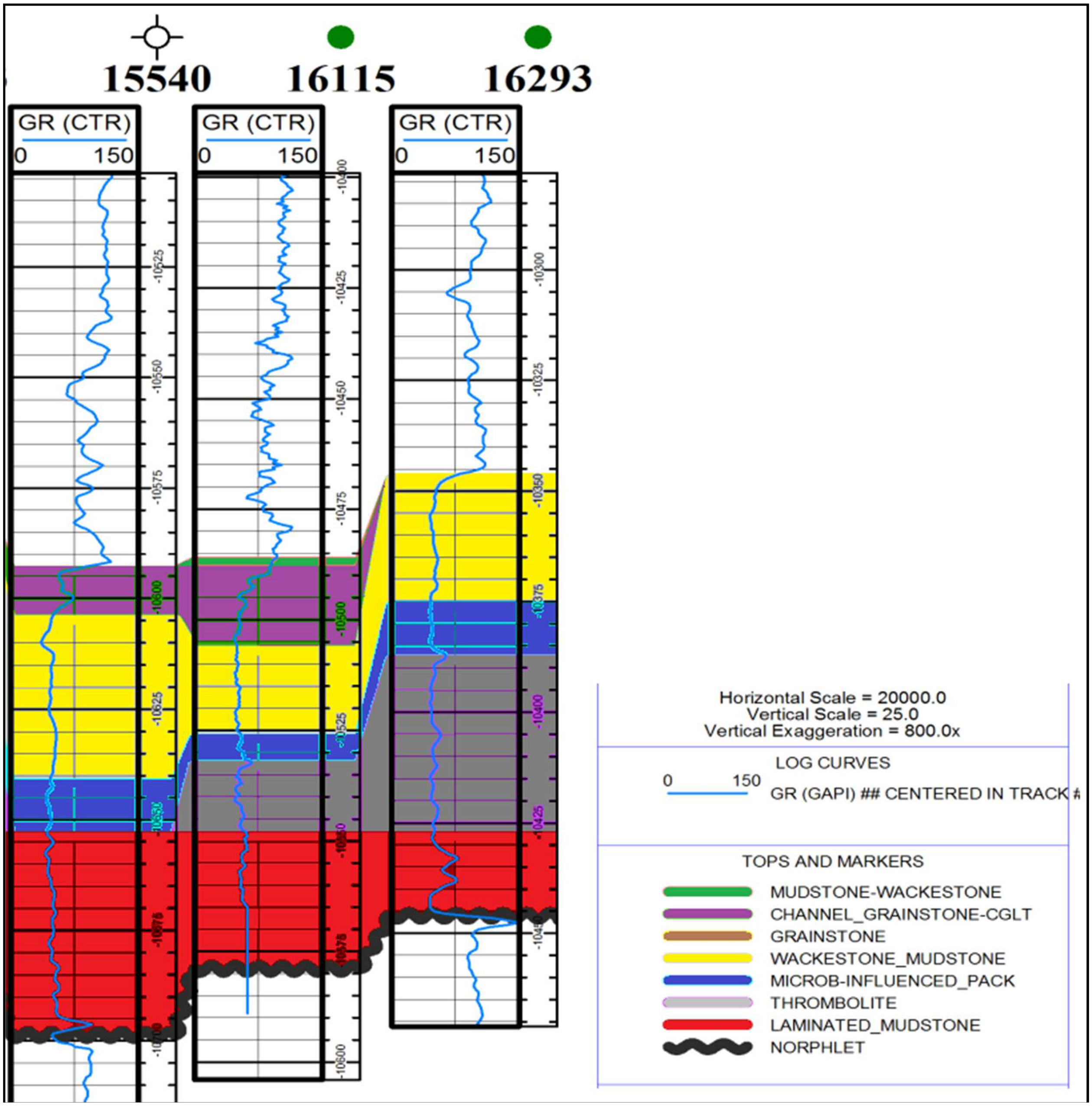


Figure 37. Stratigraphic cross-section of three wells located in LCCF. Notice that both reservoirs are not present in permit 15540 because the tidal channel is present and the S-7 facies is thick. Permit 16115 is a producing well and the S-7 facies has decreased in size and in turn the thrombolite facies reappears. Permit 16293 is producing and the tidal channel conglomerate disappears, while the S-7 decreases more in size. Allowing for the thrombolite facies to extend in thickness (modified from Ridgway, 2010)

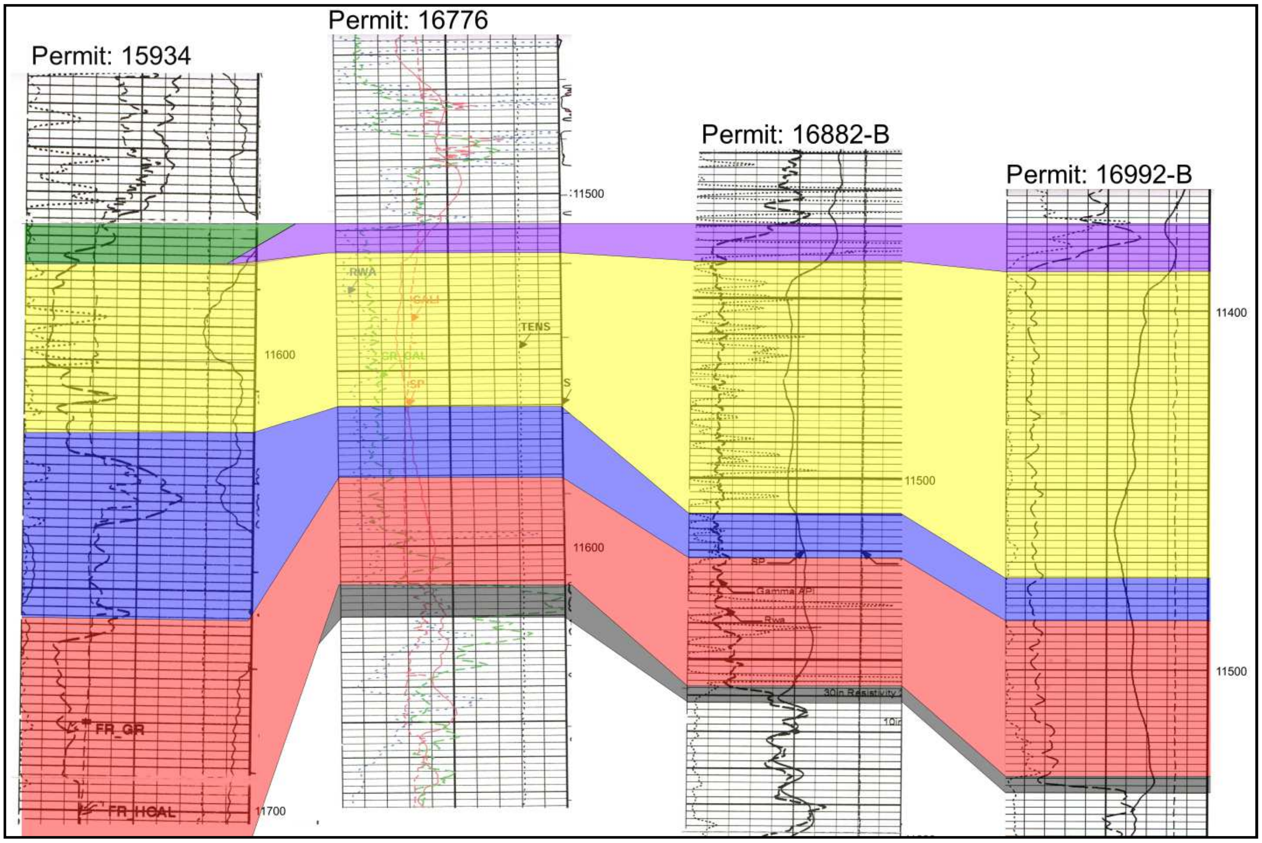


Figure 38. Stratigraphic cross-section of non-producing wells located in Brooklyn Field. Showing the relationship of the facies located in the Smackover Formation. Notice the pinchout of the peritidal lime mudstone to the tidal channel conglomerate. The marker was the contact between the S-7 facies (red) and the top of the Norphlet (green)

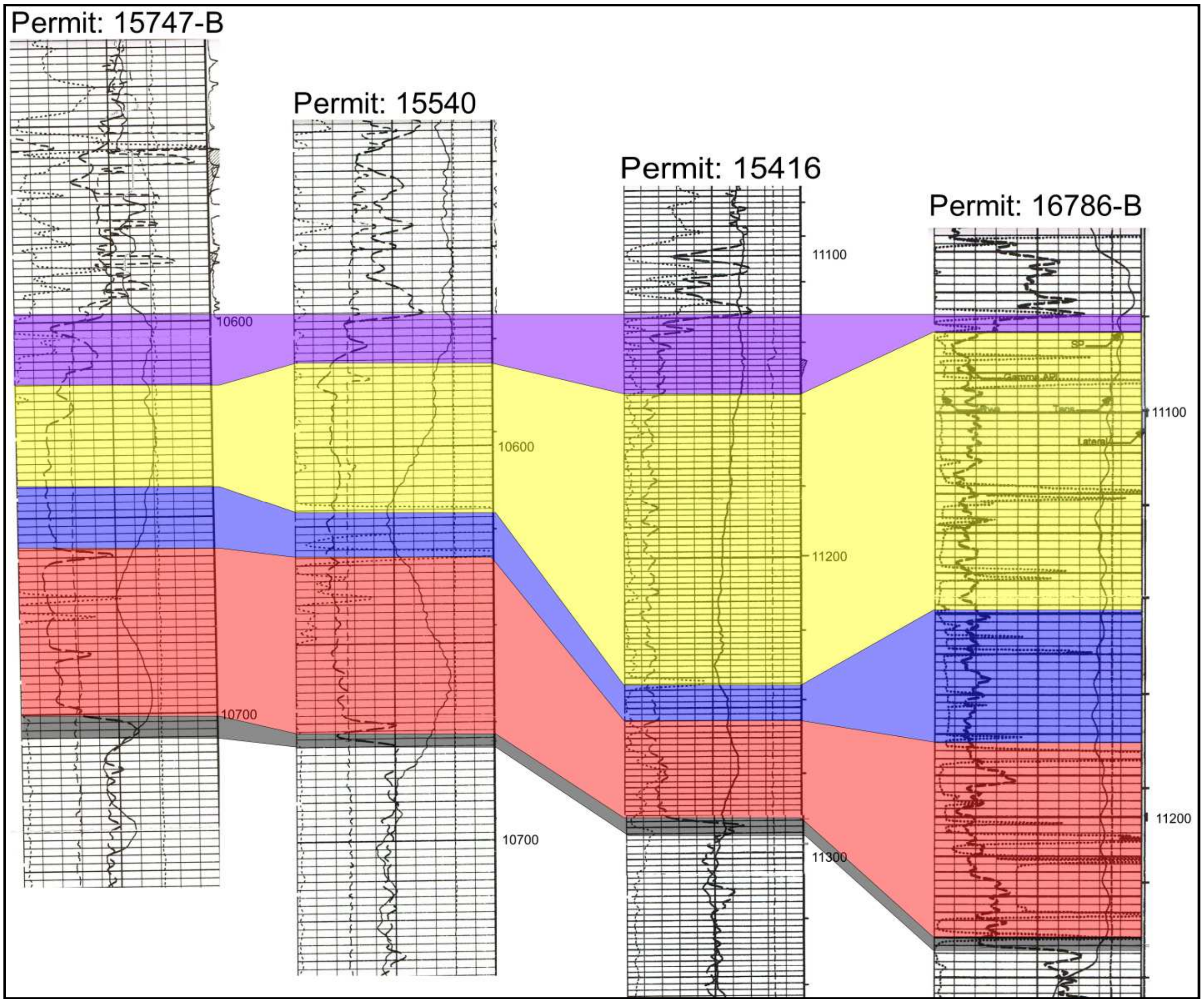


Figure 39. Stratigraphic cross-section of non-producing wells located in Little Cedar Creek Field. The direction of the wells is a southwest to northeast direction. Permit 16786-B is located in the western part of LCCF. Notice that the seal for the oolitic grainstone S-1 is not present. The marker was the contact between the S-7 facies (red) and the top of the Norphlet (green)

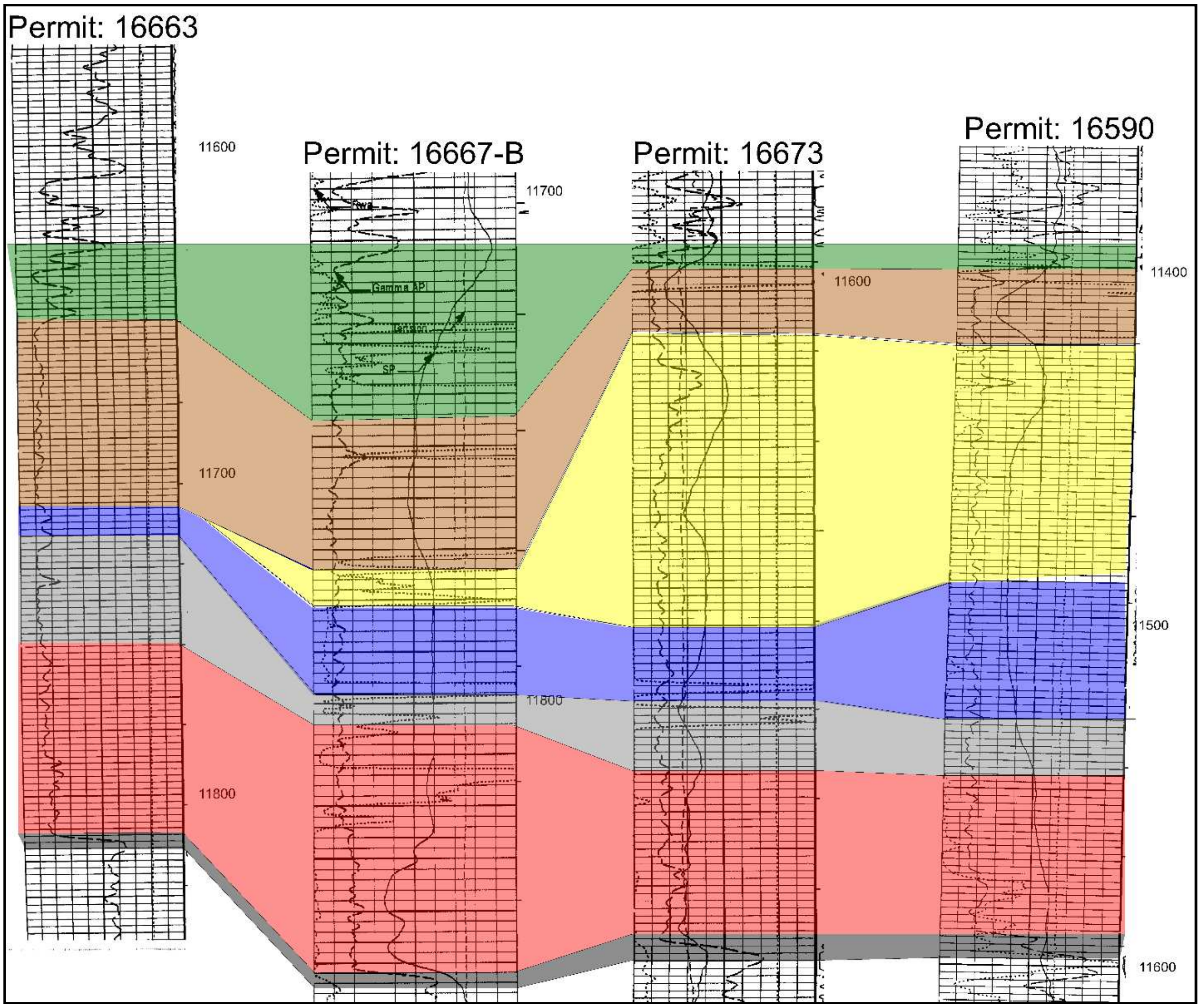


Figure 40. Stratigraphic cross-section of productive wells located in Brooklyn Field. Showing the relationship of the facies located in the Smackover Formation. Notice when the S-7 decreases or increases the thrombolite reservoir S-6 (grey) correlates to it. When the oolitic grainstone is present S-3 (brown) the tidal conglomerate (S-2) does not appear. The marker was the contact between the S-7 facies (red) and the top of the Norphlet (green)

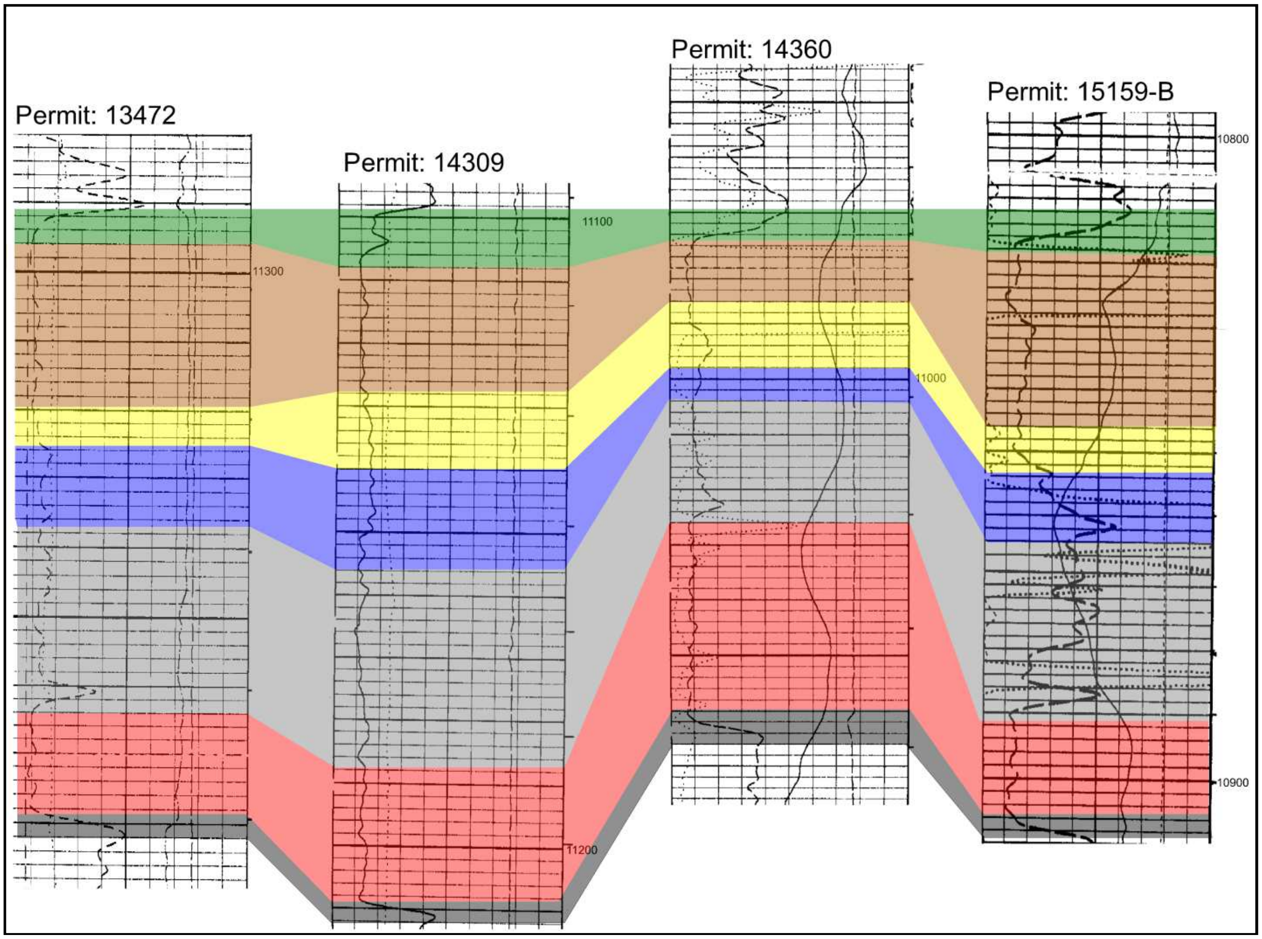


Figure 41. Stratigraphic cross-section of productive wells located in Little Cedar Creek Field. Notice when the S-7 decreases the thrombolite reservoir increases and vice versa. Instead of the tidal channel being present, the oolitic grainstone is present and the S-1 facies is present. The marker was the contact between the S-7 facies (red) and the top of the Norphlet (green)

Porosity and Permeability Feet

Porosity feet and permeability feet maps were made to better understand both reservoirs. Porosity feet, also known as net pay, represents the total pore space fluids in place. Permeability feet, also known as transmissivity, represents the ability of hydrocarbons to flow through a body rock. The net pay of the oolitic grainstone and thrombolite facies shows that the thrombolite facies has the higher net pay values, ranging from 5-6 porosity feet, but the oolitic grainstone, which ranges from 4-5.50ft is more continuous throughout both fields (Fig.42-43). SOGBA mandates that operators produce no more than 400 bopd at a max rate because LCCF and BF are competitive fields. However, (Bob Herr personal communication) who works for Pruet Production, states that some of the wells of BF could potentially flow 2-3 times higher because the permeability and porosity of the oolitic grainstone are better in BF than in LCCF. This should result in BF becoming an even larger producer of hydrocarbons than LCCF and indicates that the oolitic grainstone reservoir is the more productive reservoir. Transmissivity mirrors the net pay of the two facies because the thrombolite facies has the higher values but the continuity of the oolitic grainstone allows for hydrocarbons to flow better. This could be the reason why the net pay of the oolitic grainstone is more constant than the thrombolite facies (43-44).

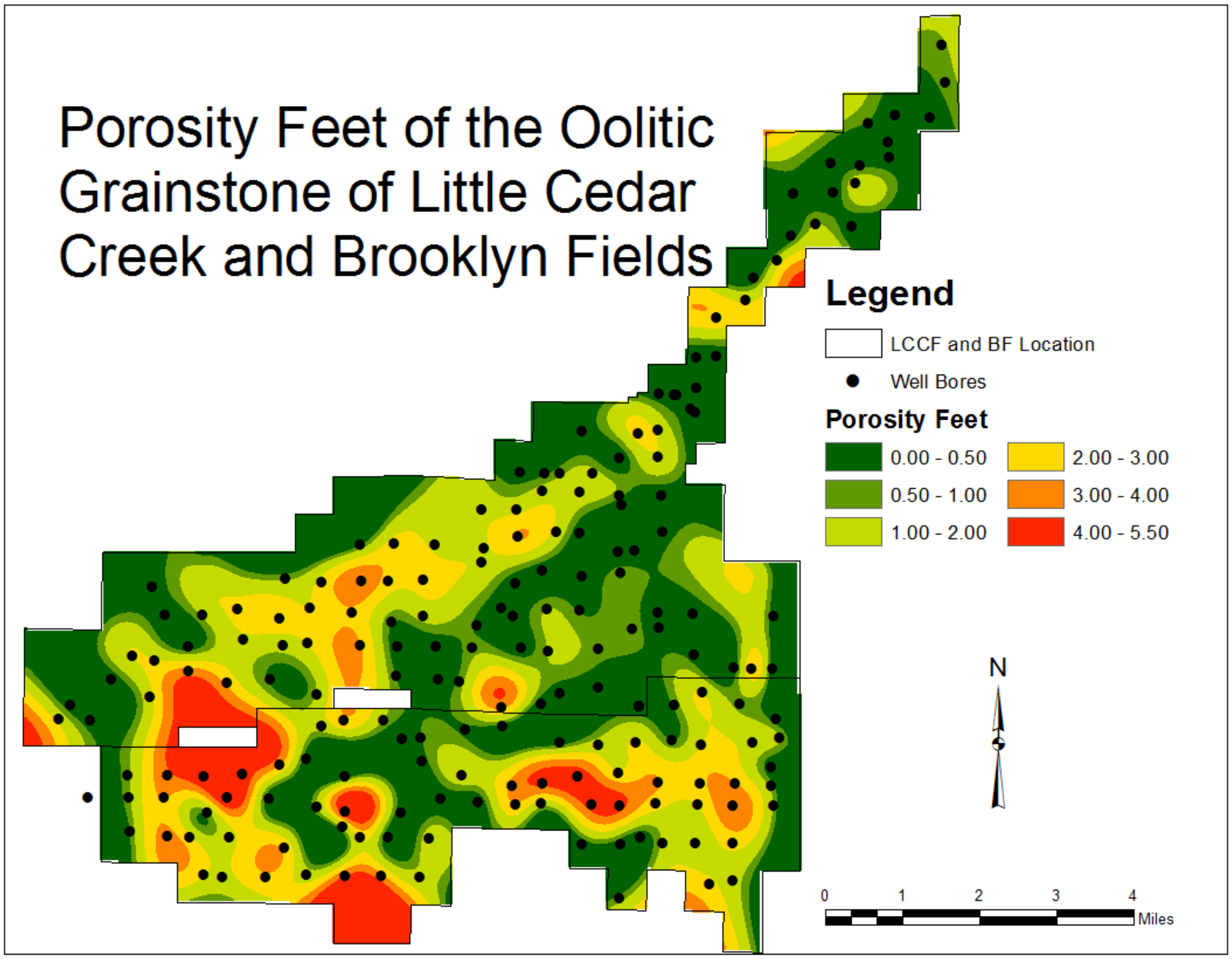


Figure 42. Porosity Feet of the oolitic grainstone of Little Cedar Creek and Brooklyn Fields

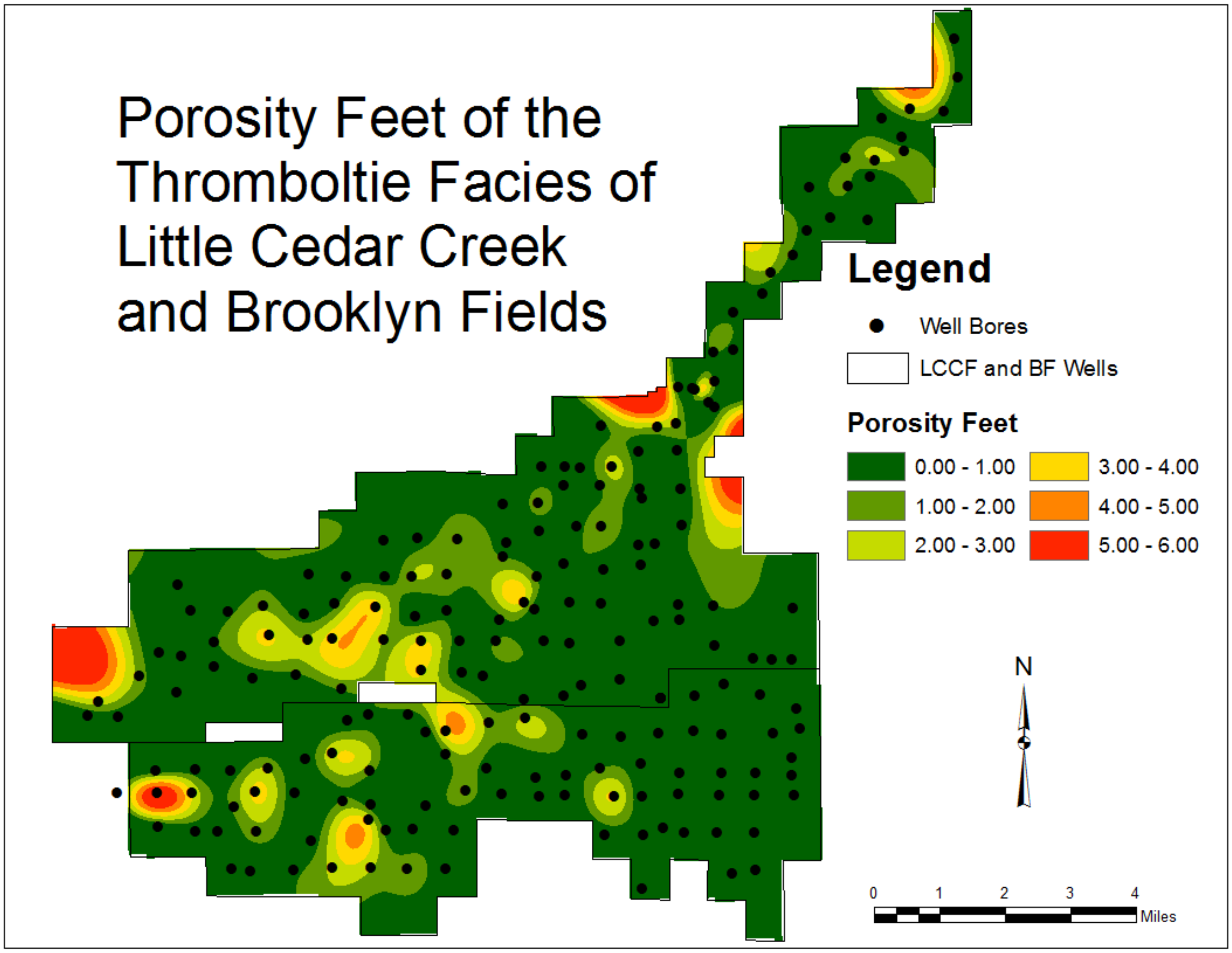


Figure 43. Porosity feet of the thrombolite facies of Little Cedar Creek and Brooklyn Fields

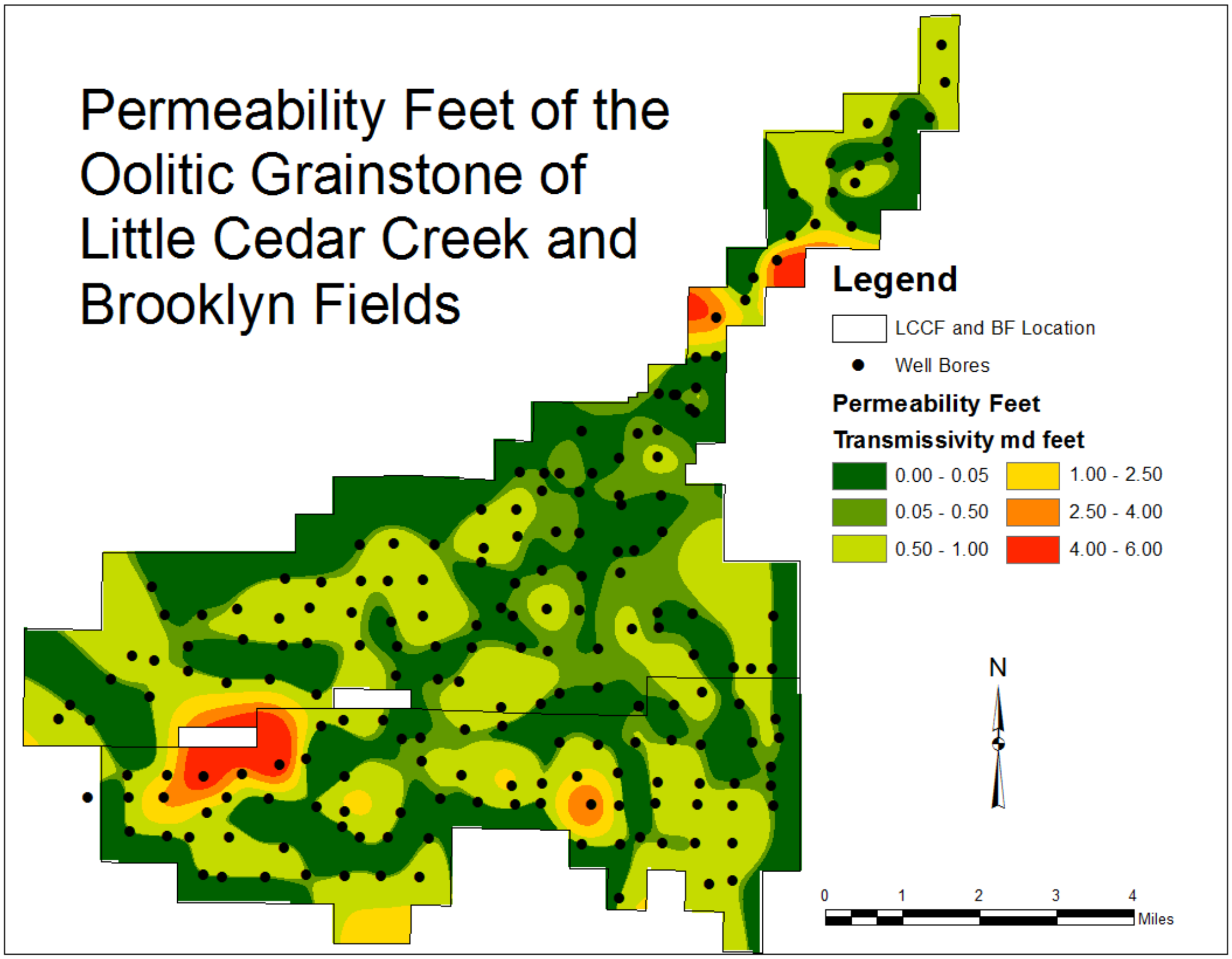


Figure 44. Permeability feet of the oolitic grainstone of Little Cedar Creek and Brooklyn Fields

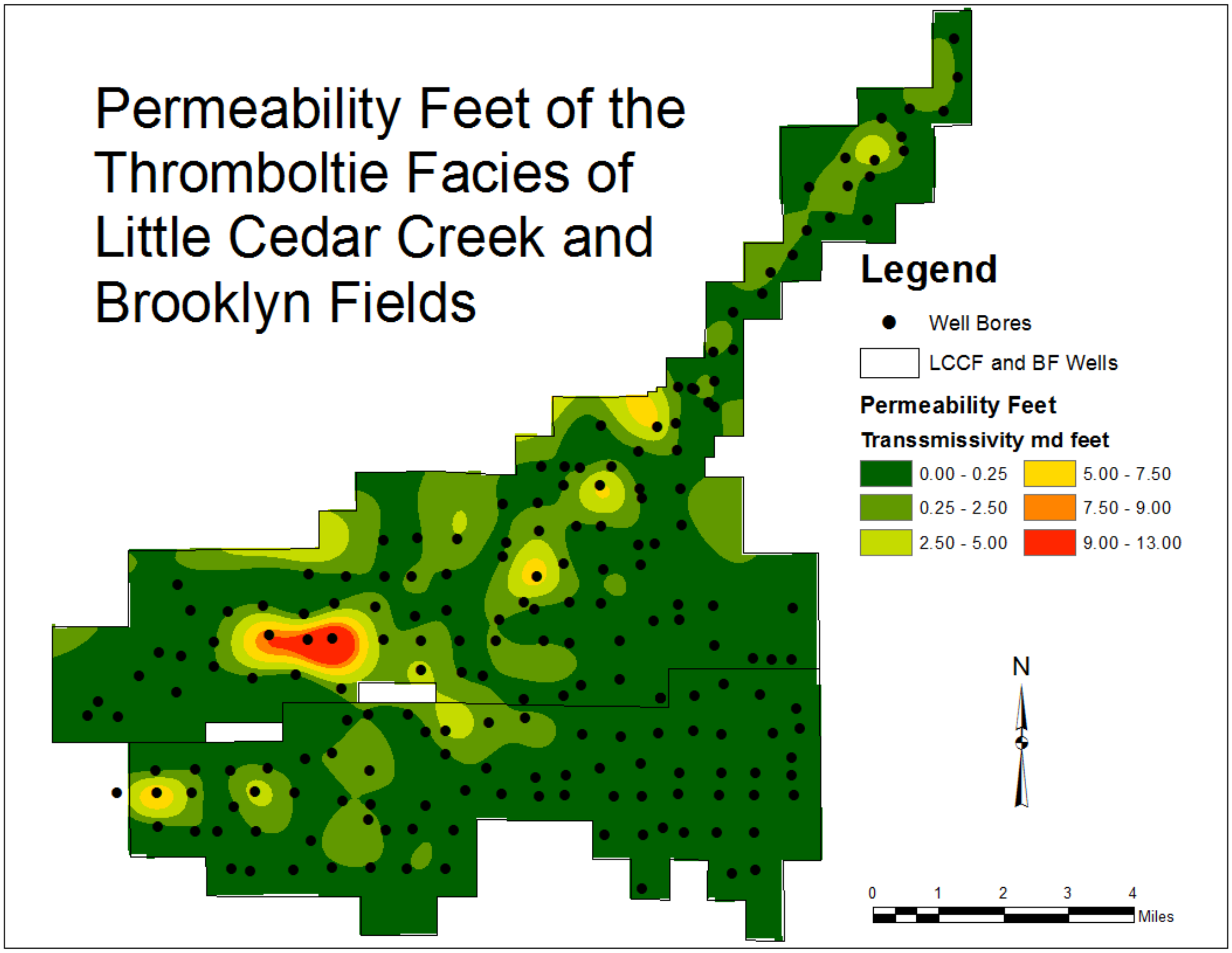


Figure 45. Permeability feet of the thrombolite facies of Little Cedar Creek and Brooklyn Fields

CHAPTER 7

CONCLUSION

1. The Little Cedar Creek and Brooklyn Fields produce out of two reservoirs the oolitic grainstone and thrombolite boundstone. These two reservoirs are not in communication with each other because they are separated from each other by an impermeabile limestone mudstone and wackestone.
2. Seven different lithofacies have been characterized in the Little Cedar Creek and Brooklyn Fields. These lithofacies are: (S-1) peritidal lime mudstone-wackestone; (S-2) tidal channel conglomeratic floatstone-rudstone; (S-3) peloid-ooid shoal grainstone-packstone (upper reservoir); (S-4) subtidal lime wackestone-mudstone; (S-5) microbially-influenced packstone-wackestone; (S-6) subtidal clotted peloidal thrombolite boundstone (lower reservoir); (S-7) transgressive lime mudstone-dolostone
3. One of the facies that affects hydrocarbon production, porosity, permeability, of the two reservoirs is the tidal channel conglomerate. When the tidal conglomerate occurs it replaces the productive ooid grainstone and is associated with a decrease in thickness of the thrombolite reservoir.
4. The S-7 facies has a stronger effect on the thrombolite reservoir than the tidal channel. The S-7 and S-6 (thrombolite) have a direct relationship to one another. S-6 begins to decrease and terminate when the S-7 starts to increase in thickness.

5. Porosity and permeability trends can be established within Little Cedar Creek and Brooklyn Fields but are not influenced by the thickness of the two reservoirs. Porosity and permeability affected by the presence of certain lithofacies that appear within the Smackover Formation.
6. Comparing the isopach maps of the oolitic grainstone and thrombolite facies to the average porosity maps is not the best method. The reason for this is because average porosity is relatively constant, meaning that if one oolitic interval is 2ft and the other is 20ft, they can still have the same average porosity. Instead, porosity feet should be map because its displays the total pore space fluids in place, indicating the best areas for potential production.
7. The average permeability and permeability feet show similar trends in the figures, but transmissivity is the better method. Permeability feet displays the ability of the fluid to flow throughout the interval. Therefore, even with a high zone of porosity feet, low transmissivity means that the fluid has no way to travel and can potentially affect production.

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VITA

Devin W. Thomas

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EDUCATION

Master of Science in Engineering Science, May, 2016
University of Mississippi, University, MS, Department of Geology and Geological Engineering
Graduate – GPA 3.77
Thesis: "The Porosity and Permeability Distribution of the Shoal Grainstone and Thrombolitic facies of the Smackover Formation in Little Cedar Creek and Brooklyn Fields in Southwestern Alabama"

Bachelor of Science in Geology, December, 2012
University of Mississippi, University, MS, Department of Geology and Geological Engineering
Undergraduate Major – GPA 3.20

WORK EXPERIENCE AND PROFESSIONAL DEVELOPMENT

Graduate Research Assistant – Mississippi Mineral Resources Institute – 2013 – Present:

- Develop structure and isopach maps by using **Rockworks** and **ArcGIS** to analyze subsurface geological and geophysical studies including petrophysical data
- Have interpreted and correlated well logs and core analysis using **Halliburton Log Viewer** to evaluate geological and geophysical data using well log analysis techniques.
- Analyze core to compile and interpret data for re-evaluation of existing oil fields in Mississippi and Alabama and determine depositional environments, and allochem properties of the different facies
- Use geoscientific workstation software Petrel and ArcGIS to assist in subsurface mapping and seismic data interpretation

Graduate Teaching Assistant – University of Mississippi, Department of Geology and Geological Engineering – 2013 – Present:

- Head Teaching Assistant and developed new labs for the Environmental Geology lab
- Lecture and reinforce learning concepts for students in Geology lab courses.
- Prepare class instructions and test and meet with students for extra learning outside of the designed lab hours.
- Manage grades and coordinate with other teaching assistants

Geographic Information Systems (GIS) technician – Mississippi Mineral Resources Institute (MMRI) – June 2013 – March 2015:

- Project funded under a grant from the Mississippi Emergency Management Act (MEMA).
- Developed over 600 map templates and map books of flood vulnerability maps using **ArcGIS**
- Collected critical facilities info and layer files to construct flood vulnerability maps
- Constructed 200 flood modeling maps of the advancement and depth of simulated floods of the Mississippi Alluvial Plain (Yazoo Basin or "Delta")
- Publication – Louis G. Zachos, Charles T. Swann, Mustafa S. Altinakar, Marcus Z. McGrath and Devin Thomas "Flood vulnerability indices and emergency management planning in the Yazoo Basin, Mississippi", International Journal of Disaster Risk Reduction

Certified in Petrel: Schlumberger Headquarters in Houston, Texas – January 2014

- Trained and completed exercise guides on seismic data interpretation, identifying subsurface structural, and stratigraphic features
- Received a certificate in **Petrel Fundamentals** computer based course at Schlumberger Headquarters in Houston,Texas

COMMUNITY AND SERVICE ACTIVITIES

University of Mississippi Football Team

- Competed five years
- Jeff Hamm Memorial Award Most Improved Offensive Player in Spring of 2009
- Team captain of the running backs in 2011-2012

Relay for Life

- Team Captain
- Pushed the team to raise an excess of $2000 in 2011
- Have raised over $4000 since 2011

Mclean Mentors Program

- 6 week mentoring program
- Help build college aspirations for Mississippi youth
- Tutor and mentor elementary and middle school students

Watch D.O.G.S (Dads of Great Students)

- Provide positive male role models for elementary students
- Provide another set of eyes and ears to enhance security and prevent bullying.
- Assist by car pooling and opening car doors for incoming students
- Go to classrooms and assist the teacher with daily task

PROFESSIONAL AFFILIATIONS

American Association of Petroleum Geologists, Student Member, Former Treasure and Founder of Ole Miss AAPG Chapter
Society of Petroleum Engineers, Student Member,
Society of Exploration Geophysicists, Student Member,
National Association of Black Geoscientists, Student Member
Society of Sedimentary Geology, Student Member
Houston Geological Society, Student Member
Shreveport Geological Society, Student Member
Alpha Phi Alpha Fraternity Incorporated, Alumni

HONORS AND AWARDS

Geology Awards

Outstanding Graduate Student of the Year – University of Mississippi Geology and Geological Engineering	2016
SPE Star Fellowship recipient for the Eastern North America Region	2015
National Association of Black Geoscientist Scholarship	2015
Shreveport Geological Society Scholarship	2015
Houston Geological Society Calvert Memorial Scholarship	2015
National Association of Black Geoscientist Scholarship	2014
Shreveport Geological Society Scholarship	2014
AAPG J. Ben Carsey Sr. Memorial Grant	2014
Outstanding Junior of the Year – University of Mississippi Geology and Geological Engineering	2011

Educational Awards

SEC Brad Davis Community Service Postgraduate Scholarship	2012
SEC Academic Honor Roll	2012
Who's Who Among College Students	2011
SEC Academic Honor Roll	2010

University of Mississippi Athletic Association Honor Roll	2010
SEC Academic Honor Roll	2009
University of Mississippi Athletic Association Honor Roll	2009
SEC Academic Honor Roll	2008
University of Mississippi Athletic Association Honor Roll	2008

Honor Societies

Omicron Delta Kappa Society	2012
Gamma Beta Phi Honor Society	2009
National Society of Collegiate Scholars	2009
Alpha Lambda Delta	2008

Community Service Awards

Algernon Sydney Sullivan Award Finalist	2014
SEC Community Service Player of the Week	2012
Allstate AFCA Good Works Team Nominee	2012

Athletic Awards

Clower-Walters Scholarship Outstanding Senior Football Player	2013
Arthur Ashe Sports Scholar Award	2011
Arthur Ashe Sports Scholar Award	2010
National Football Foundation Scholar-Athlete Award	2009